Exhibit VII A – Engineering Report: Water Supply System

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4-400 D2 Engineering Report: Water Supply System

October 2019

Waukesha Water Utility
SERVING WAUKESHA SINCE 1886

GREELEY AND HANSEN

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EXECUTIVE SUMMARY

The City of Waukesha Water Utility (WWU) provides water treatment and distribution services to a service area that includes the City of Waukesha (Waukesha), portions of the Town of Waukesha, and the City of Pewaukee. The St. Peter Sandstone aquifer, which has been the primary source of drinking water for Waukesha, has been severely depleted and is contaminated with naturally-occurring radium. Waukesha needs a long-term, sustainable alternative to its existing water supply to protect public health. After study efforts and public engagement, the Great Lakes-St. Lawrence River Basin Water Resources Council (Compact Council) issued its Final Decision unanimously approving Waukesha's Application to source water from Lake Michigan. WWU subsequently commissioned the Great Water Alliance (Program) to transition Waukesha's water supply. The following Program Elements are required to supply Waukesha with Lake Michigan water:

- **Water Connections to Water Supplier:** Connections will be required to draw water from the Milwaukee Water Works (MWW) Distribution System. The piping and supporting connections have been called the Station Suction Pipelines.
- **Oklahoma Pumping Station (OPS):** An OPS will be required to provide the head necessary to convey water to Waukesha through the Water Supply Pipeline.
- **Water Supply Pipeline and Appurtenances:** A Water Supply Pipeline will be needed to convey water from the OPS to the water reservoirs at the Booster Pumping Station (BPS).
- **Water Reservoirs:** Water reservoirs will be required between the OPS and Waukesha to attenuate demands and provide for storage. An air break at the water reservoirs will be used to prevent backflow from the water reservoirs in the event of Water Supply Pipeline failure.
- **Booster Pumping Station (BPS):** A BPS will be required to provide the head necessary to convey flow from the water reservoirs to the Water Supply Control Building (WSCB).
- **Chemical Feed Facilities:** Chemical feed facilities will be required at the BPS to provide the ability to adjust water quality characteristics, such as residual disinfectant levels.
- **BPS Discharge Pipeline:** A BPS Discharge Pipeline will be required to convey flow from the BPS to the WSCB.
- **Water Supply Control Building (WSCB) and Water Connection to Waukesha:** A WSCB will be required to maintain discharge pressures to within desirable ranges for WWU's distribution system. Connections will be required downstream of the WSCB to supply WWU's Distribution System with Lake Michigan water.

Under the Wisconsin Administrative Code, Department of Natural Resources (NR), Chapter 108.04(2)(a), "All final plans and specifications submitted to the department pursuant to s. 281.41, Stats., and s. NR 108.03, shall be accompanied by a request for approval and by information pertinent to the design of the system, including general plans, construction details, specifications and an engineering report." The purpose of this Engineering Report: Water Supply System (Report) is to satisfy this requirement for the above Program Elements being implemented as part of the Program by summarizing the approach used for making key design decisions that supported the development of the drawings and specifications, including the following:

- The approach for modeling steady state hydraulics, developing system curves, designing pipe size, test pressures, pumps, storage, pressure class, and restrained joints.
- Key design philosophies for the pumping stations and pipelines.
- The approach for modeling transient hydraulics, determining the type, size, and location for pipeline appurtenances required to mitigate hydraulic transients, and providing provisions for air management.

The focus of this Report has been placed on Waukesha's new water supply system. Engineering reports for the Station Suction Pipelines and OPS will be submitted separately by MWW.

Route Study and Field Investigations

A route study was completed for the pipelines. Route alternatives were identified between a new OPS located on the southeast quadrant of Oklahoma Avenue and 76th Street, the new BPS located on the southwest quadrant of Swartz Road and Racine Avenue in the City of New Berlin, and the new WSCB located on the northwest quadrant of Les Paul Parkway and Sunset Avenue in Waukesha. The route alternatives were evaluated based on economic and non-economic evaluation criteria and scored via a Triple Bottom Line analysis guided by the Envision Rating System for Sustainable Infrastructure. Route Alternative M1 shown in **Figure ES-1** was selected as the preferred route. Field investigations, including site survey, geotechnical, environmental, wetlands, waterways, endangered resources, and cultural resources were subsequently completed to support design.

Water Demand and Steady State Hydraulics

Waukesha's new water supply system was sized to convey Waukesha's water demand as follows:

- **Water Supply Pipelines:** **15.1 million gallons per day (MGD)**, which is equivalent to the firm capacity of the OPS. The firm capacity of the OPS was determined in coordination with MWW based on MWW's operational preferences to supply sufficient demand to the reservoirs when periods of maintenance are needed which limit the hours of operation. The firm capacity is greater than the anticipated maximum day demand (MDD) of 13.6 MGD during a year where the average day demand (ADD) is the same as that approved by the Compact Council of 8.2 MGD.
- **BPS, Storage, and: Chemical Facilities** **15.75 MGD**, which was determined in coordination with WWU and is equivalent to Waukesha's existing peak hour demand (PHD).
- **BPS Discharge Pipeline:** **19.0 MGD**, to accommodate future expansion of the BPS firm capacity to a flow rate equivalent to Waukesha's anticipated PHD during a year where the ADD is the same as that approved by the Compact Council of 8.2 MGD.
- **WSCB:** **19.0 MGD**, to accommodate future expansion of the BPS firm capacity to a flow rate equivalent to Waukesha's anticipated PHD during a year where the ADD is 8.2 MGD.

A steady state hydraulic model for the facilities and pipelines was developed based on the pipeline alignment and facility layouts. Hydraulics were simulated from static conditions (no flow) to the design capacities listed above. From the hydraulic analysis, a 30-inch Water Supply Pipeline and a 36-Inch BPS Discharge Pipeline sizes were selected. System curves were developed to support pump and valve selection at facilities. Pipeline test pressures were determined in accordance with American Water Works Association (AWWA) C600, and pipe pressure classes and restrained joints were designed to accommodate the test pressures.

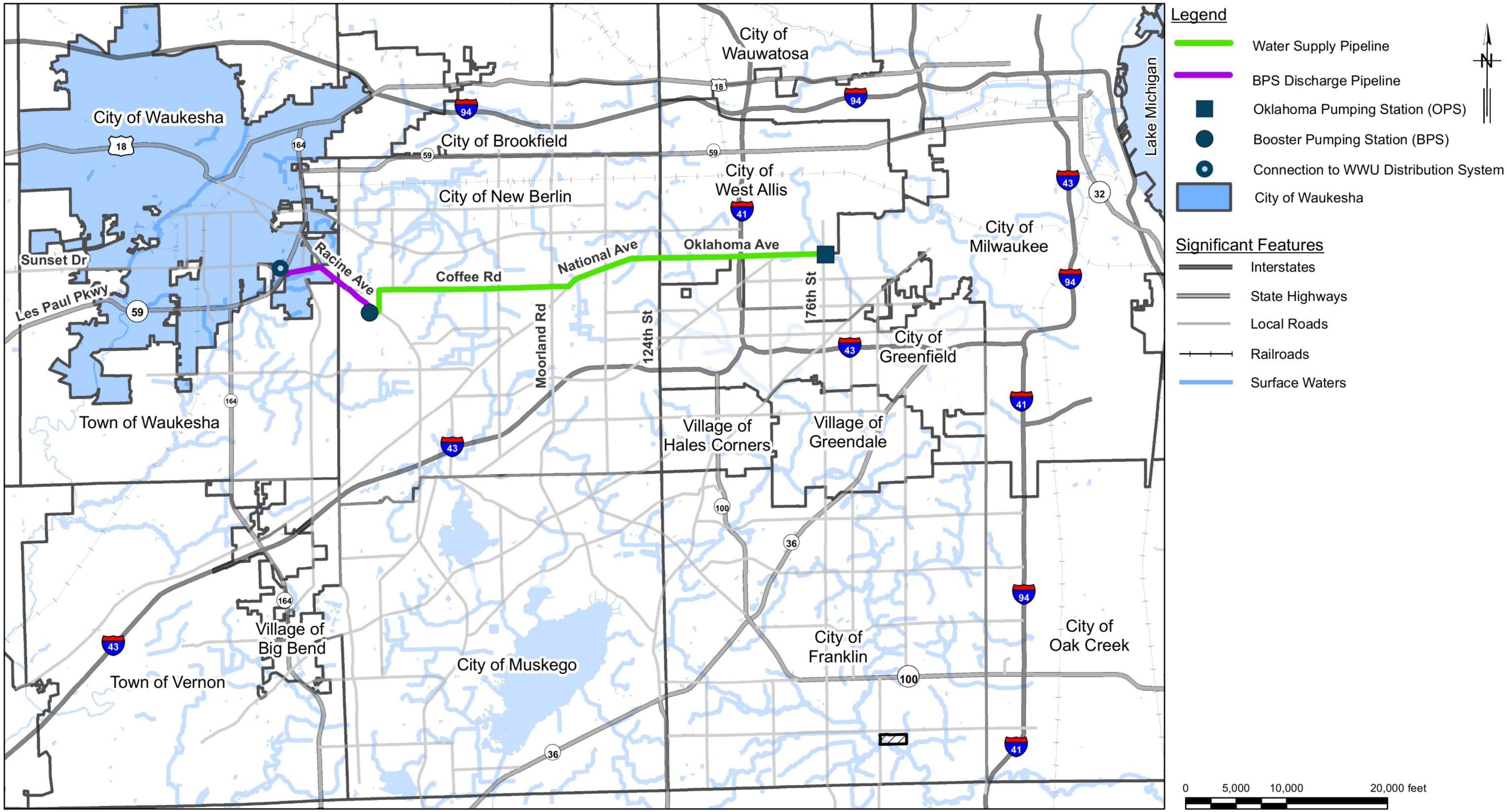

Figure ES-1 Water Supply System Pipeline Routes and Facilities

Design Philosphy, Pipelines

Pipe materials and joints were designed based on pipe size, hydraulics, constructability, WWU familiarity with material, and cost. To mitigate corrosion and provide for a longer service life, the pipelines were designed with two layers of polyethylene encasement – an inner layer consisting of V-Bio® Enhanced Polyethylene Encasement and an outer layer of standard polyethylene encasement, as well as sacrificial galvanic magnesium anodes, bonded joints, and test stations. The test stations will allow the ability to periodically monitor for corrosive signatures during operations so that proactive corrosion mitigation measures can be implemented if needed.

The horizontal and vertical alignments were developed for the pipelines considering pipe materials, joints, and construction methods, including open-cut and trenchless construction. Construction methods were selected based on surface features, existing utilities, and cost. Trenchless construction was utilized where open-cut construction was not specifically preferred due to surface features or permit requirements. Horizontal and vertical alignments of the pipelines were designed beyond pavement where feasible to reduce cost due to pavement replacement, flowable or select fill, and maintenance of traffic. Trenchless construction via jacking and boring was utilized as a means of mitigating surface disruption at rail and major road crossings and horizontal directional drilling (HDD) was utilized to cross waterways, select wetlands, and some roads. Limits of construction were designed to accommodate the construction method and pipeline appurtenances.

Pipeline appurtenances were designed for operations and maintenance as follows.

- **Isolation Valves:** The pipelines were designed with butterfly valves that will serve to isolate portions of the pipelines for maintenance and repair scenarios. Isolation valves were placed at approximately two-mile intervals, while some valves were shifted towards trenchless construction segments to minimize additional restrained joint length. Isolation valves were designed to be direct-buried except where specifically required to be located in vaults by the Wisconsin Administrative Code.
- **Blow-Off Assemblies:** Blow-off assemblies, consisting of a tee, branch, gate valve, and riser pipe, were placed at local low points in the vertical alignments to provide a means for draining the pipelines during startup, maintenance, or repair scenarios.
- **Air Valve Assemblies:** Air valves were placed at local high points along the vertical alignments to provide provisions for air management and transient mitigation. The air valve assemblies were designed in vaults with provisions for accessing the inside of the pipelines for inspection purposes at maximum intervals of 8,000 feet.

Design Philosophy, Facilities

Water Reservoirs

The water reservoirs will provide operational, equalization, and emergency storage and an air break between the MWW and WWU Distribution Systems. The effective storage capacity of the water reservoirs was determined to be 16.0 million gallons (MG) based on operational, equalization, and emergency storage. Two, 210-foot diameter circular, at grade, precast prestressed concrete water reservoirs with a side water depth of 33 feet were selected. The water reservoirs will have an inlet pipe rising 6-inches above the high water level to provide an air break from the Water Supply Pipeline. The water reservoirs were designed with a hydrodynamic mixing system to avoid dead zones, short circuiting, vertical stratification, and provide turnover to maintain water quality and assist in chemical addition.

Booster Pumping Station (BPS)

The BPS will utilize vertical turbine type pumps to convey water to the WWU Distribution System. Four pumps will be provided with three operating pumps and one standby pump. Each pump will have a 5.25 MGD capacity and discharge head of 145 feet and the BPS will have a firm capacity of 15.75 MGD.

Vertical turbine pumps were evaluated along with horizontal split case pumps. Vertical turbine pumps were selected due to the smaller footprint and subsequent cost savings in the capital cost for the BPS. Although the BPS will be provided with an initial firm capacity of 15.75 MGD, provisions for future expansion have been considered to accommodate the 19.0 MGD PHD associated with the approved 8.2 MGD ADD. These two options include replacing two of the pumps with higher capacity pumps or replacing all four pumps with higher capacity pumps. There is sufficient space and electrical capacity for this upgrade in the future when it is required.

To satisfy the minimum hour demand of 1.2 MGD, a recirculation line was designed to allow the pumps to stay above the minimum flow rate on the pump curve by recirculating flow from the discharge header to the suction header. Each pump will have a variable frequency drive to adjust pump speed and maintain the target hydraulic grade line (HGL) of 1,120 feet in the BPS Discharge Pipeline at the BPS. In the event of a failure or power outage, standby power will be provided by an on-site natural gas-fueled generator. The BPS will include security measures, including site access control and cameras.

Chemical Feed Facilities

Chemical feed facilities were designed based on the required chemical dosing at the BPS from the findings from a year-long pipe loop test. Chloramine will be used for disinfection, which is consistent with the disinfectant used by MWW. Sodium hypochlorite and liquid ammonium sulfate (LAS), the two components needed to create chloramine, will be dosed at two points, the water reservoir recirculation line and the BPS discharge line. Two chemical rooms will house bulk storage and day tanks, along with associated chemical equipment.

Water Supply Control Building (WSCB)

The WSCB will house one 10-inch and two 14-inch pressure sustaining and reducing valves (PSRVs) to maintain pressure above 35 psi along the BPS Discharge Pipeline and reduce pressure to within the current operating HGL of the WWU Distribution System's Central Pressure Zone. The WSCB will also house the pressure reducing valve (PRV) interconnection between the Southeast Highline BPS and the BPS Discharge Pipeline to provide a hydraulic connection to Hunter Tower. In the event the BPS Discharge Pipeline pressure drops, such as in the event of sudden BPS pump stoppage or pipeline maintenance or failure, the PRV will open to allow flow from the Southeast Highline BPS or Hunter Tower to the BPS Discharge Pipeline and maintain maintaining pressure in the BPS Discharge Pipeline and at the BPS.

Leakage Testing, Disinfection, and Commissioning

The Wisconsin Administrative Code does not provide requirements specific for sequencing and disinfecting a long transmission main system with multiple facilities. A method for sequencing disinfection and commissioning of Waukesha's new water supply system has been developed and is included in this Report. The contractors could employ a different method during construction to more efficiently and effectively complete the work. However, key requirements necessary for the disinfection of Waukesha's new water supply system have been specified in order to support the successful completion of the water supply transition and allow the same or comparable disinfection methods to be implemented. Each contractor will be responsible for providing leakage testing in accordance with AWWA C600, disinfection in accordance with AWWA C651, and commissioning of infrastructure within the limits of their contract package. Constraints were specified in order to reduce the effort to maintain chlorine residual and pressure by the contractors prior to commissioning and to mitigate the potential for requiring the disinfection of a given Program Element to be repeated. Payment will be withheld from the contractor until after completion of disinfection.

Transient Hydraulics and Air Management

A transient hydraulic model for the facilities and pipelines were developed in Liquid Transients (LIQT) software based on the pipeline alignments and facility layouts. Hydraulics were simulated for a sudden loss of power and stoppage of pumping while conveying the design capacities of the pipelines and facilities. Transient mitigation devices in the form of air valve assemblies were designed along the pipelines to mitigate hydraulic transients. Air valve assemblies were designed to maintain capacity during normal operation by releasing entrained air and by accommodating filling and emptying during startup and maintenance.

SECTION 1 Introduction

1.1 Purpose

Under the Wisconsin Administrative Code, Department of Natural Resources (NR), Chapter 108.04(2)(a) – Requirements For Plans And Specifications Submittal For Reviewable Projects And Operations Of Community Water Systems, Sewerage Systems And Industrial Wastewater Facilities: Plans for Reviewable Projects, Submission of Final Plans and Specifications, "All final plans and specifications submitted to the department pursuant to s. 281.41, Stats., and s. NR 108.03, shall be accompanied by a request for approval and by information pertinent to the design of the system, including general plans, construction details, specifications and an engineering report." The purpose of this Engineering Report: Water Supply System (Report) is to satisfy this requirement for the City of Waukesha's (Waukesha's) new water supply system being implemented as part of the Great Water Alliance (Program).

Under the Wisconsin Administrative Code, Department of Natural Resources, Chapter 811.09(4) – Requirements for the Operation and Design of Community Water Systems: Specific Requirements for Waterworks, Plans, Specifications and Engineering Reports, Engineering Report Requirements, this Report has been developed to include basis of design items applicable to Waukesha's new Lake Michigan water supply system. This Report summarizes the approach used in making key design decisions that supported the development of the drawings and specifications for the Program's water supply system facilities and pipelines, and has been organized as follows to satisfy NR 811.09(4). The Report requirements per NR 811.09 are included with the cover letter.

1. **Section 1: Introduction**, including Program background and water supply system purpose and description.
2. **Section 2: Pipeline Route and Field Investigations**, including Program location, route study, field investigations, and utility coordination used to support design.
3. **Section 3: Steady State Hydraulics**, including population, demand projection, design flow rates, topography, and the approach for modeling steady state hydraulics used to determine pipe and pump size, normal operating conditions, test pressures, pipe pressure class, restrained joint design, and special coating requirements.
4. **Section 4: Design Philosophy, Pipelines**, including the approach for designing pipelines and supporting equipment and appurtenances.
5. **Section 5: Design Philosophy, Facilities**, including the approach for designing facilities and supporting equipment and appurtenances.
6. **Section 6: Leakage Testing, Disinfection, and Commissioning,** including the approach for developing criteria and sequencing for specifying leakage testing, disinfection, and commissioning requirements.
7. **Section 7: Transient Hydraulics and Air Management**, including the approach for modeling transient hydraulics and determining the type, size, and location for pipeline appurtenances required to mitigate hydraulic transients and manage air.
8. **Section 8: Program Water Supply System Costs**, including the Opinion of Probable Construction Cost (OPCC) and the Operation, Maintenance, and Replacement (OM&R) costs and for the Program's water supply system.
9. **Section 9: Conclusions**, including a summary of key design aspects of the water supply system.
10. **Section 10: References,** including a list of references used in the design of the water supply system.

For information on work in floodplains and wetland impacts, refer to the Wetland and Waterway Impact Permit Application submitted to the Wisconsin Department of Natural Resources (WDNR) in June 2019.

1.2 Great Water Alliance Overview

The City of Waukesha Water Utility (WWU) provides water treatment and distribution services to a service area that includes Waukesha, portions of the Town of Waukesha, and the City of Pewaukee. The St. Peter Sandstone aquifer, which has been the primary source of water for Waukesha has been severely depleted in Southeast Wisconsin and is contaminated with naturally occurring radium. This is due in large part to a natural layer of shale rock that restricts groundwater recharge. Depletion of the St. Peter Sandstone aquifer has caused increases in the concentrations of radium and other contaminants. As a result, Waukesha needs a long-term, sustainable alternative to its existing water supply to protect public health.

In 2009, the Department of Justice (DOJ) issued a Stipulation and Order for Judgment to WWU to enforce state drinking water radionuclide standards. In October 2013, following study efforts and public engagement, Waukesha resubmitted its Application for Lake Michigan Diversion with Return Flow (Application) to WDNR. In it, Lake Michigan water was determined to be the only reasonable sustainable source of water that protects both the environment and public health. WDNR concurred that Waukesha's proposal met the criteria of the Great Lakes-St. Lawrence River Basin Water Resources Compact (Compact) and submitted the Application to the Great Lakes-St. Lawrence River Basin Water Resources Council (Compact Council) for review. In its Final Decision, dated June 21, 2016, the Compact Council unanimously approved Waukesha's Application to source water from Lake Michigan as Waukesha's only reasonable water supply alternative.

WWU commissioned a team to implement the Program to transition Waukesha's water supply to Lake Michigan water. The purpose of the Program is to plan, design, construct, and commission infrastructure with a 100-year useful life necessary to transition Waukesha's water supply. Approximately 11-miles of transmission main with pumping facilities, water reservoirs, and chemical treatment will deliver water from Lake Michigan to Waukesha from the City of Milwaukee (Milwaukee). Approximately 23-miles of main is required by the Compact Council's Final Decision to achieve a net zero water balance in the Great Lakes–St. Lawrence River Basin. Refer to **Figure 1-1** for the Program vicinity map.

Key Program Elements associated with Waukesha's water supply transition were identified, as listed below following the flow path along the water supply and return flow systems shown in **Figure 1-2**. Some of these Program Elements have been designed and will be bid under the contract packages shown in **Figure 1-2**.

- **Water Connections to Water Supplier:** Connections will be required to draw water from the Milwaukee Water Works (MWW) Distribution System. The piping and supporting connections have been called the Station Suction Pipelines.
- **Oklahoma Pumping Station (OPS):** An OPS will be required to provide the head necessary to convey water to Waukesha through the Water Supply Pipeline.

Engineering reports for the Station Suction Pipelines and OPS will be submitted by MWW.

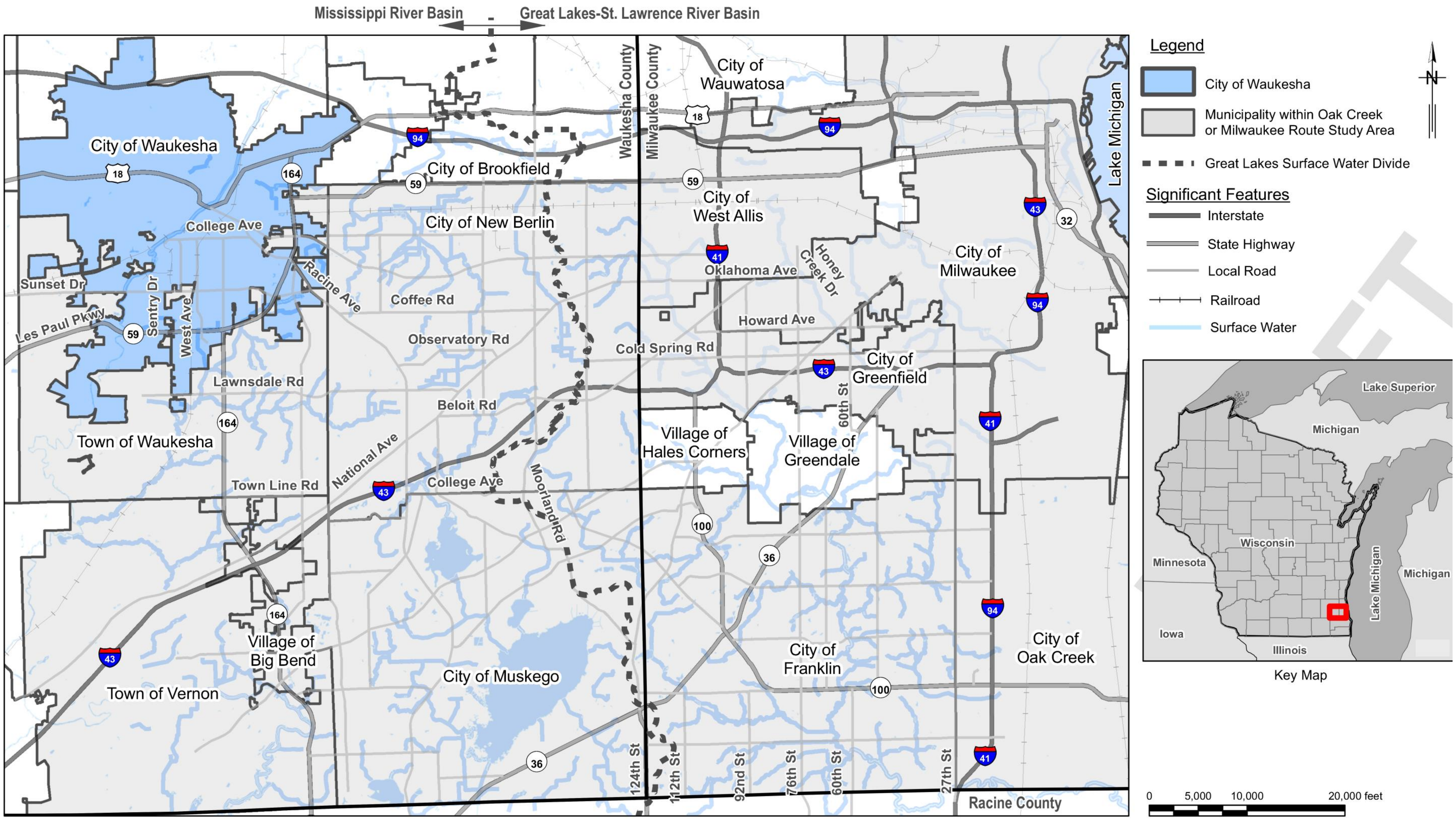

Figure 1-1 Program Vicinity Map

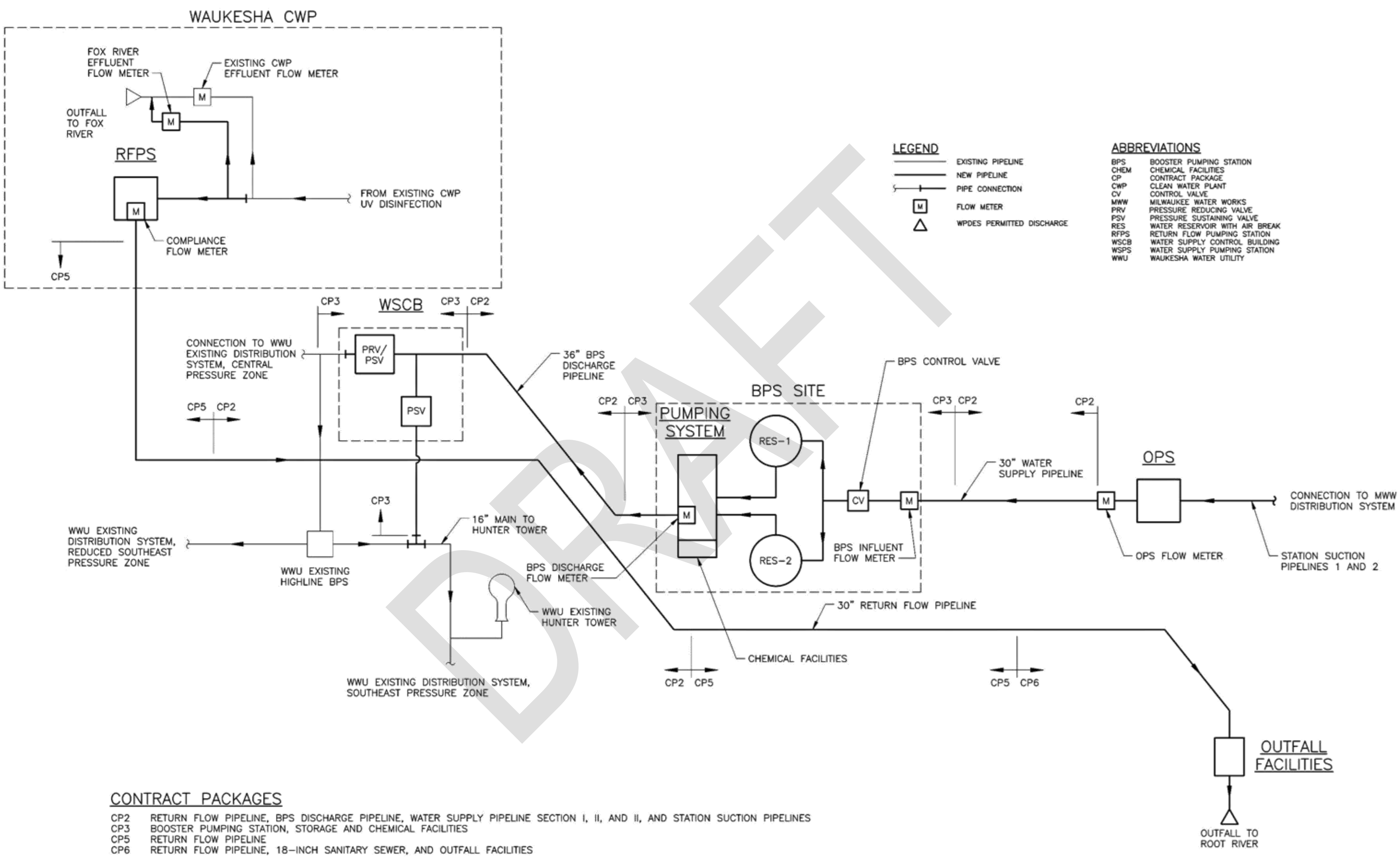

Figure 1-2 Program Diagram

The following Program Elements are the focus of this Report:

- **Water Supply Pipeline and Appurtenances:** A Water Supply Pipeline will be needed to convey water from the OPS to the water reservoirs at the Booster Pumping Station (BPS).
- **Water Reservoirs:** Water reservoirs will be required between the OPS and Waukesha to attenuate demands and provide for storage. An air break will be provided at the water reservoirs to prevent backflow from the water reservoirs in the event of Water Supply Pipeline failure.
- **Booster Pumping Station (BPS):** A BPS will be required to provide the head necessary to convey flow from the water reservoirs to the Water Supply Control Building (WSCB).
- **Chemical Feed Facilities:** Chemical feed facilities will be required at the BPS to provide the ability to adjust water quality characteristics, such as residual disinfectant levels.
- **BPS Discharge Pipeline:** A BPS Discharge Pipeline will be required to convey flow from the BPS to the WSCB.
- **Water Supply Control Building (WSCB) and Water Connections to Waukesha:** A WSCB will be required to maintain discharge pressures to within desirable ranges for WWU's Distribution System. Connections will be required downstream of the WSCB to supply WWU's Distribution System with Lake Michigan water.

Other Program Elements include the following:

- **WWU Distribution System Improvements:** WWU's Distribution System is currently supplied by geographically disperse groundwater wells. The new water supply will feed the distribution system from one connection point. Distribution system modeling has indicated immediate improvements are not required to satisfy existing demand.

  Note the water supply transition of WWU's Distribution System is being completed by others and is not part of the Program. Discussions with WDNR have indicated a separate engineering report will be required for this effort that would include information such as the following:

  - WWU Distribution System information that identifies which infrastructure is to be used for emergency conditions.
  - Preparation details for the source water transition, including pipe loop testing, unidirectional flushing, scale analysis, public education, sampling schedule and reporting plan.
  - Control testing anticipated following source water transition, including scale analysis, radium, lead, and copper testing at consumer taps, and operational adjustments.
  - The long-term sampling and reporting plan, including the plan for continued radium, lead, and copper monitoring at consumer taps, unidirectional flushing, customer complaint summaries and actions to resolve, and proposed reporting frequency until such time that the system has re-stabilized following the transition.
- **Return Flow Pumping Station (RFPS):** A RFPS will be required to provide the head necessary to convey highly treated effluent from Waukesha's Clean Water Plant (CWP) to the Root River. The RFPS will be owned and operated by Waukesha's Department of Public Works.

- **Return Flow Pipeline and Appurtenances:** A Return Flow Pipeline will be required to create a net zero water balance in the Great Lakes–St. Lawrence River Basin. The Return Flow Pipeline will begin at the RFPS at Waukesha's CWP. As stipulated in the Final Decision, the Return Flow Pipeline will discharge into the Root River on Parcel 9489998001, southeast of the intersection of Oakwood Road and 60th Street in the City of Franklin.
- **Outfall Facilities:** Facilities at the Root River outfall will be used to provide a means for discharging highly treated effluent to the Root River. A reaeration structure will be provided to provide dissolved oxygen adjustment prior to discharge. The Root River ultimately discharges into Lake Michigan, thereby returning the borrowed water back to the source.

SECTION 2 Pipeline Route and Field Investigations

2.1 Route Study

A route study was completed to determine a route for the BPS Discharge and Water Supply Pipelines. The following subsections summarize the background and route study for the pipelines. Refer to the Wetland and Waterway Impact Permit Application submitted to WDNR in June 2019 for details summarizing the route study.

2.1.1 Background

In the Application, the City of Oak Creek (Oak Creek) was the preferred Lake Michigan water supplier. In late 2016, six possible pipeline routes and facility locations were considered in a screening-level analysis for an Oak Creek water supply with a Return Flow Pipeline to the Root River. Based on an economic and non-economic evaluation, three of the six route alternatives were selected and further evaluated as part of the Route Study: Oak Creek (Oak Creek Route Study), which was used to identify the preferred route that will be used to return highly treated effluent to the Root River through the Return Flow Pipeline.

Milwaukee had not agreed to negotiate as a potential water supplier at the time of the Compact Application but, in 2017, provided an unsolicited proposal to supply water to Waukesha. Milwaukee was then selected to be the Lake Michigan water supplier for the Program due to cost savings to WWU ratepayers. The Route Study: Milwaukee (Milwaukee Route Study) was subsequently completed to evaluate additional water supply corridors for a Milwaukee water supply. The route for the Return Flow Pipeline to the Root River remained consistent with the route selected from the Oak Creek Route Study. The following subsections summarize the Milwaukee Route Study completed for the BPS Discharge and Water Supply Pipelines.

2.1.2 Starting and Ending Points of Connection

Route alternatives were identified between known or potential points of connection for the pipelines as described in the following subsections. Each connection point location provided boundary conditions for the route study area and will serve as the starting and ending points of the pipelines.

2.1.3 Water Supply Pipeline Connection to Water Supplier

From discussions with MWW, it was anticipated at the time of the Milwaukee Route Study that the point of connection to the MWW Distribution System would be located at 60th Street and Howard Avenue, and that a new Water Supply Pumping Station (WSPS) would be located in proximity to the anticipated point of connection. The WSPS would be supplied from an existing 54-inch trunk main that runs beneath 60th Street. In this configuration, the WSPS would also serve as the Water Supply Pipeline's starting point. For the purposes of the Milwaukee Route Study, the location of the WSPS and point of connection to the MWW Distribution System was the intersection of 60th Street and Howard Avenue. As of the date of this Report, the anticipated location of the WSPS has changed to the southeast quadrant of 76th Street and Oklahoma Avenue due to land availability, while the connection point to the MWW Distribution System is anticipated to be located on Oklahoma Avenue just east of Honey Creek. The WSPS has been renamed the OPS and will be supplied through two, new 24-inch Station Suction Pipelines, which will be supplied from existing 16- and 24-inch mains that run beneath Oklahoma Avenue. The anticipated locations have not changed the preferred route, and only serve to make the preferred route even more preferable than the other route alternatives.

2.1.4 Water Supply and BPS Discharge Pipeline Connections to Water Reservoirs and Booster Pumping Station

The Water Supply Pipeline will discharge into new water reservoirs upstream of its connection to WWU's Distribution System. The water reservoirs will be utilized to attenuate demands and provide for emergency storage. A new BPS will be required to provide the head necessary to convey flow from the water reservoirs to WWU's Distribution System. Site screening was performed for potential locations for the water reservoirs and BPS. It was determined the water reservoirs and BPS would be located in Minooka Park, southwest of the intersection of Racine Avenue and Swartz Road in the City of New Berlin (New Berlin) on Parcel NBC 1224994 owned by the Waukesha County Department of Parks and Land Use. The site was selected due to land availability in coordination with the Waukesha County Department of Parks and Land Use and topography. The site is located at a relatively higher elevation along the water supply system, which reduces the need for re-pumping. Refer to **Section 5.2.1** for details on site selection.

Parcel NBC 1224994 is shown on **Figure 2-1**. The property will serve as the location for the water reservoirs and BPS. For the purposes of the Milwaukee Route Study, the water reservoirs served as the ending point of the Water Supply Pipeline and the BPS served as the starting point of the BPS Discharge Pipeline.

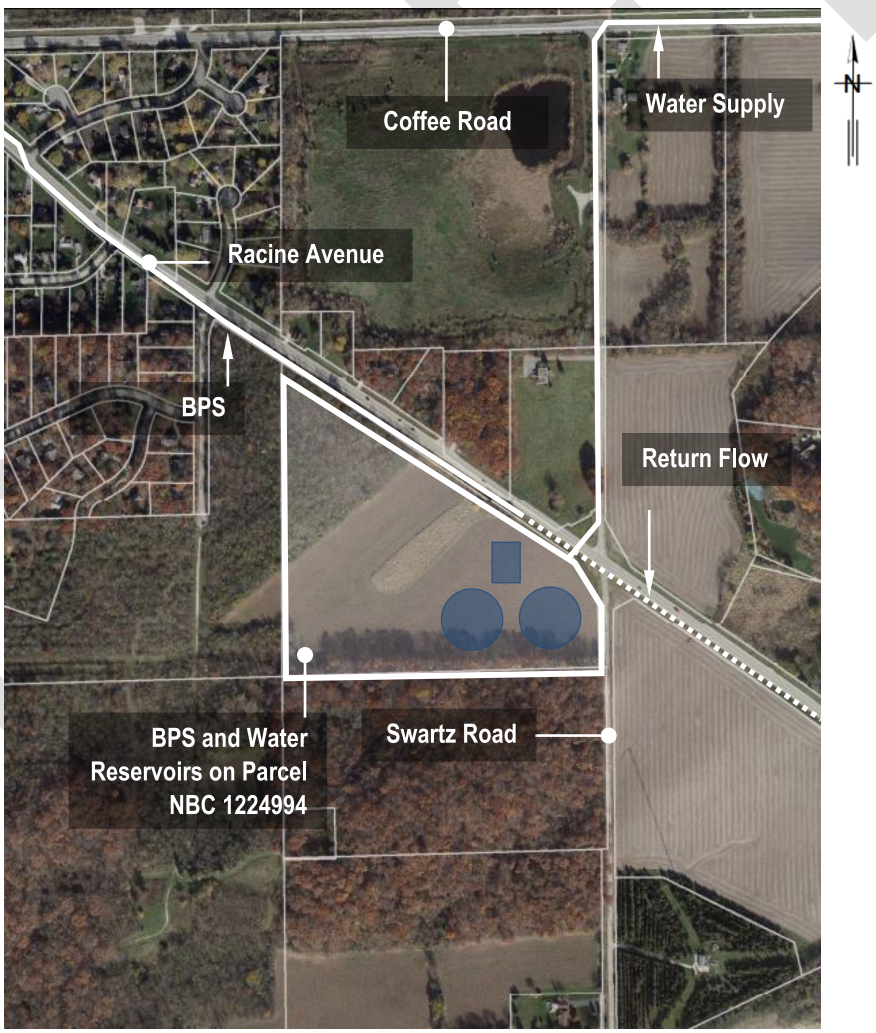

Figure 2-1 Water Reservoirs and Booster Pumping Station Location

2.1.5 BPS Discharge Pipeline Connection to Water Supply Control Building

Downstream of the water reservoirs and BPS, the BPS Discharge Pipeline will connect to the WSCB, which will connect to WWU's Distribution System along Les Paul Parkway at a 24-inch trunk main. Distribution system modeling was performed as part of the Program to evaluate the preferred connection point to WWU's Distribution System. The evaluation included four alternative connection points. The alternatives were evaluated based on distribution system improvements required to accommodate each connection point, available land to locate the WSCB, and cost. The potential points of connections were discussed with WWU and it was determined that the connection point at Les Paul Parkway and Sunset Drive is preferred due to its proximity to Parcel WAKC 1349999 owned by WWU that will be used to locate the new WSCB. Refer to **Section 5.4.1** for details on the site selection.

The connection location is shown on **Figure 2-2**. For the purposes of the Milwaukee Route Study, the BPS Discharge Pipeline ended at the connection to the WSCB at the intersection of Les Paul Parkway and Sunset Drive.

Figure 2-2 Waukesha Water Utility Distribution System Connection

2.1.6 Evaluation Criteria

Route alternatives were evaluated on the basis of economic and non-economic evaluation criteria. Non-economic evaluation criteria include characteristics or special requirements associated with each route alternative. The economic and non-economic evaluation criteria include the following items:

- Hydraulic analysis
- Total pipeline length
- Trenchless requirements
- Geotechnical conditions
- Contaminated materials
- Maintenance of traffic requirements
- Wetlands
- Waterways
- Floodplain encroachment
- Endangered resources
- Protected resources
- Agricultural resources
- Energy consumption
- Stakeholder feedback
- Real property and easement requirements
- Constructability
- Conceptual OPCC

The criteria were evaluated based on desktop assessments, field reconnaissance studies, and public Open House Meetings in which the public provided input on route alternatives. Preliminary horizontal alignments, special crossings which require trenchless construction, and steady state hydraulics were developed to compare the route alternatives on an economic basis. Class 4 OPCCs were prepared in accordance with AACE International's Recommended Practice No. 18R-97. Costs were developed at an Engineering News-Record Construction Cost Indices (ENR CCI) value of 10,942 for June 2017 with a contingency of 25 percent and rounded to the nearest hundred thousand dollars. Based on the economic and non-economic evaluation, Route Alternatives M1, M2, and M3 shown in **Figure 2-3** were selected for further evaluation. Note that the nature of the existing right-of-way between the BPS and the WSCB eliminated the need to evaluate route alternatives for the BPS Discharge Pipeline.

Route Alternatives M1, M2, and M3 were further evaluated based on Key Performance Indicators (KPIs), which were used to refine the evaluation to incorporate the concepts of a Triple Bottom Line (TBL) analysis guided by the Envision Rating System for Sustainable Infrastructure. KPIs were developed to integrate WWU's values into the design process and provide a basis for developing metrics to evaluate and compare route alternatives. The KPI definitions were developed to be broad enough to apply to all aspects of the Program and act as universal weighting criteria. WWU staff weighted the KPIs from one (to represent a less significant or lower perceived impact to the Program) to ten (to represent a more significant or higher perceived impact to the Program). The weights were linearly scaled such that the sum of all weights produced a sum of 100. The KPIs were weighted from one (to represent a KPI of less importance) to ten (to represent a KPI of greater importance) to allow the evaluation to consider WWU preferences. The KPIs are listed by descending weight in **Table 2-1** alongside their definition using language from the Envision Rating System for Sustainable Infrastructure.

Data and information from the economic and non-economic evaluation were used to develop metrics for the KPIs. These metrics, in conjunction with input and feedback obtained during the Open House Meetings with stakeholders, were quantified and assigned to corresponding KPIs. **Table 2-2** displays the metrics selected and the KPIs to which they were assigned.

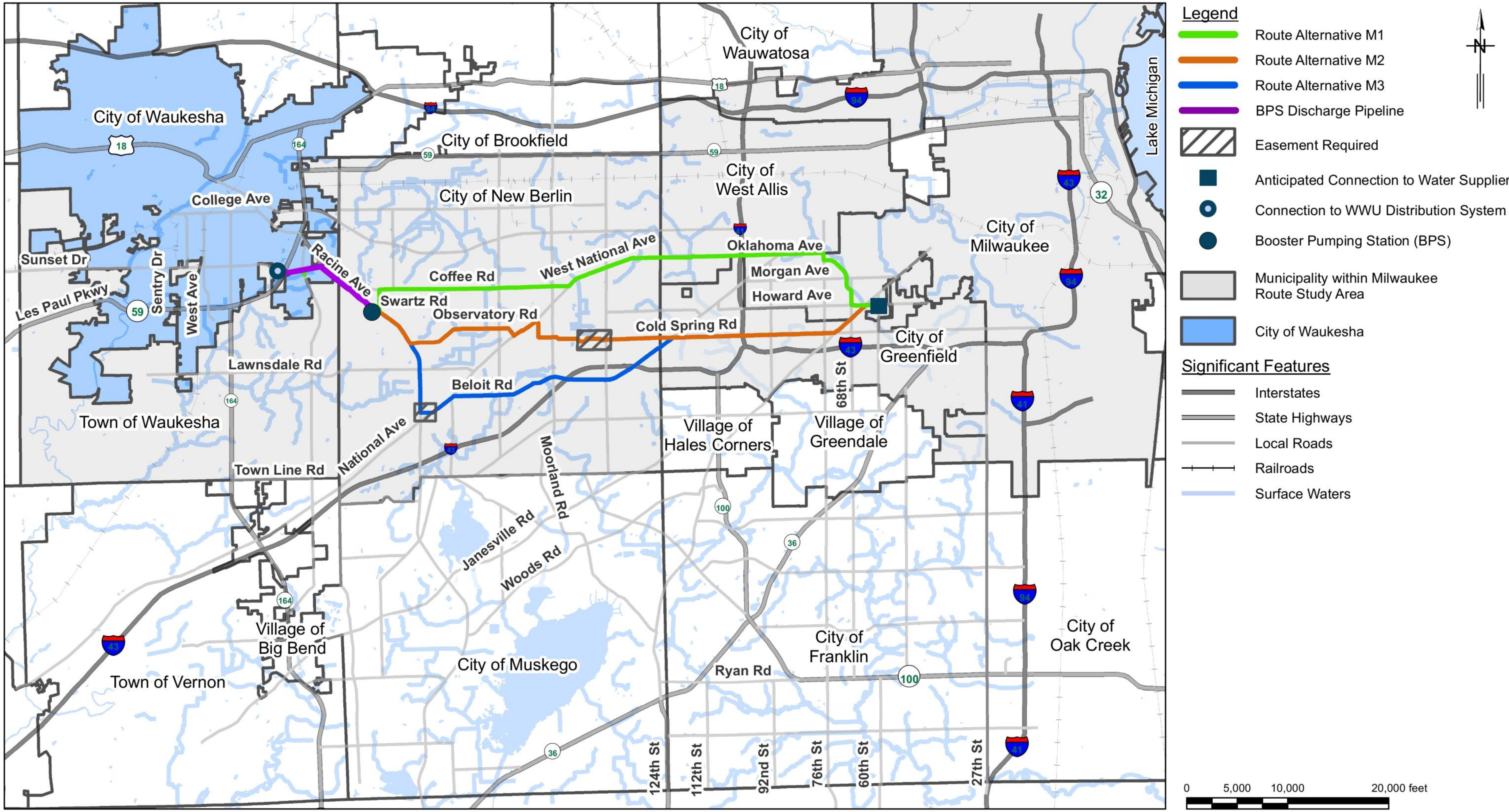

Figure 2-3 Route Alternatives M1, M2, and M3

Table 2-1 Key Performance Indicator Summary

Key Performance Indicator	Definition	Weighting
System Reliability	Using robust design strategies, preventive maintenance and intuitive configurations, Program Elements are dependable and resilient.	19.0
Life Cycle Cost	Pursue strategies that reduce long-term operational and maintenance costs.	15.5
Schedule	Complete the Program in a timeframe that mitigates negative impacts on the community's quality of life.	14.0
Ease of Construction	Avoid sites that require intensive efforts to preserve or restore, integrate infrastructure, or access with construction equipment.	11.0
Public Acceptability	The Program vision and goals align with those of the affected communities, and the implementation of the Program expands the skills, capacity, mobility, and health of a community while mitigating negative impacts.	6.5
Capital Cost	Minimize financial impact on the community with consideration of factors such as resource conservation, ease of infrastructure integration, and avoiding site development that requires additional efforts to preserve.	6.0
Effects on Ability to Finance	Through triple-bottom line analysis, Program Elements have been de-risked and future-proofed, helping attract infrastructure investment.	6.0
Future Expansion	Implement designs and other measures that allow for the expansion of the Program to incorporate Compact Council approved future connections and increased flow without requiring additional infrastructure and capital expenditure.	6.0
Operational Flexibility	Reduce vulnerabilities by creating an adaptable design that can function in a variety of social, economic, and environmental conditions with monitored systems that allow ease and consistency of operation.	6.0
Environmental Impact	Measures are taken to preserve the natural world through avoidance, monitoring, restoration, and negative impact mitigation; resources are conserved during the construction and operation of the Program; there is a concerted effort to preserve the ambient conditions that affect quality of life of the community like noise, light, and air quality.	5.0
Cost Sharing Potential	Thorough infrastructure integration and commitment to synergistic opportunities, the cost of Program Elements is shared by a broader community.	5.0
	Total	**100.0**

Table 2-2 Metrics Delineated into KPIs

Key Performance Indicator	Metrics
System Reliability	Length of Pipe (LF), Accessibility (Number of Special Crossings, Number of Easements), Maximum Pressure (psi)
Life Cycle Cost	Capital Cost (Dollars), Energy Cost (Dollars)
Schedule	Days (Determined by Linear Feet of Pipe / Day)
Ease of Construction	Depth to Bedrock (LF of Pipe < 50ft deep), Dense Soils (LF of Pipe), Organic Soils (LF of Pipe), Shallow Groundwater, Soils Corrosive to Steel/Ductile Iron (LF of Pipe), Soils Corrosive to PCCP (LF of Pipe), Contaminated Materials (Total Ranking Score on each Route)
Public Acceptability	Cultural Resources (No. of Archaeological, Burial, and Historic Sites), Transportation (Linear Feet of Roadway Impacts, Square Footage of Pavement Area, Additional Driving Hours), Number of Easements, Agriculture (Acreage in the Easements), Coordination with Planned Regional Transportation Projects
Capital Cost	Capital Cost (Dollars)

Key Performance Indicator	Metrics
Effects on Ability to Finance	Envision Score[1]
Potential Future Expansion[2]	Growth potential within City of Waukesha, Number of Municipalities Traversed, Average Day Demand of Municipalities Traversed (MGD)
Operational Flexibility	Number of Pressure Sustaining Valves, Number of Connections to the Distribution System, Distribution System Pressure (psi)
Environmental Impact	Acreage of Wisconsin Wetland Inventory (WWI) Mapped and Photo-Interpreted Wetlands, Number of Waterways Crossed
Cost Sharing Potential	Number of Municipalities Traversed, Simultaneous Planned Regional Transportation Projects

Notes:
1. Sustainable projects are more likely to receive financing from different entities.
2. Potential future expansion of Waukesha's water system would need to be approved by the Compact Council.

2.1.7 Route Evaluation

The TBL evaluation incorporates three dimensions of performance: social and community, economic, and environmental. The KPIs were delineated into the dimensions of performance to which they best corresponded. Route Alternatives M1, M2, and M3 were scored from one (to represent a less favorable alternative for the established KPI) to five (to represent a more favorable alternative for the established KPI) based on each route alternative's performance for each evaluation criteria. These scores were entered into the TBL matrix shown in **Table 2-3**. The resulting products of the weighting and scores were compiled to produce a total score for each route shown at the bottom of the matrix where a higher score indicates a more preferable route alternative.

Table 2-3 Triple Bottom Line Evaluation for the Route Alternatives M1, M2, and M3

	Criteria	Weighting[1]	Maximum Possible Score	Route Alternative M1	M2	M3
1	**Social and Community Goals**					
1.1	Schedule	14.0	5	3	2	2
1.2	Public Acceptability	6.5	5	5	2	3
1.3	Operational Flexibility	6.0	5	3	3	3
1.4	Future Expansion	6.0	5	3	3	4
2	**Economic Goals**					
2.1	System Reliability	19.0	5	3	3	3
2.2	Life Cycle Cost	15.5	5	3	3	2
2.3	Ease of Construction	11.0	5	4	2	3
2.4	Capital Cost	6.0	5	3	3	2
2.5	Effects on Ability to Finance	6.0	5	4	2	3
2.6	Cost Sharing Potential	5.0	5	3	3	4
3	**Environmental Goals**					
3.1	Environmental Impact	5.0	5	3	3	3
	Net TBL Score[2]	**100**	**500**	**330**	**263**	**276**
	Percent of Max Possible Score		-	**66%**	**53%**	**55%**

Notes:
[1] Weighting = Criteria internal weighting factor divided by sum of internal weighting factors x 100.
[2] Net TBL Score = Sum product of criteria score x weighting for each alternative. Net TBL Scores were rounded to nearest whole number.

The highest-weighted KPIs are System Reliability, Life Cycle Cost, Schedule, and Ease of Construction. Route Alternatives M1, M2, and M3 scored the same with respect to the highest-weighted KPI, System Reliability. Route

Alternatives M1 and M2 scored the same in the second highest-weighted KPI, Life Cycle Cost. Route Alternative M2 scored less preferably than Route Alternative M1 in the third highest-weighted KPI, Schedule. Route Alternative M2 also scored less preferably than other two route alternatives in the fourth highest-weighted KPI, Ease of Construction, as well as in Public Acceptability and Effects on Ability to Finance. The low scoring of Route Alternative M2 is principally attributed to anticipated stakeholder challenges and constructability through more narrow, residential corridors. These corridors would also require additional maintenance of traffic and result in additional driving hours and driving distance for residents, and have the most easement requirements of any of the route alternatives. Furthermore, Route Alternative M2 has a higher OPCC than Route Alternative M1 and several considerations could further increase the cost associated with Route Alternative M2 due to the potential for additional pipeline length if the required easement is not able to be acquired, as well as additional surface restoration or utility relocation. Many of these factors also pose risks to slowing progress during construction. Considering economic and non-economic factors, Route Alternative M2 is less preferable than Route Alternatives M1 and M3.

Although Route Alternative M3 scored more preferably than Route Alternative M2, Route Alternative M3 has a higher OPCC than the other two route alternatives due to its longer pipeline length and special crossing requirements. Route Alternative M3's length along areas of suspected shallow bedrock also poses a risk to further increasing capital costs. Route Alternative M3 scored less preferably than the other two route alternatives in the second highest-weighted KPI, Life Cycle Cost, due to additional energy costs attributed to pumping water along a longer pipeline length. Although Route Alternative M3 avoids the use of narrow corridors west of Beloit Avenue, it still utilizes Cold Spring Road east of Beloit Avenue which would require additional maintenance of traffic requirements, as well as stakeholder and constructability challenges through more narrow corridors. If either Route Alternatives M2 or M3 utilized the High Voltage Electrical Transmission Utility Corridor between Forest Home Avenue and 94th Street, Route Alternatives M2 and M3 would still have higher OPCCs and require more travel time and distance due to maintenance of traffic than Route Alternative M1.

Route Alternative M1 reduces the challenges associated with Route Alternatives M2 and M3 by routing through Oklahoma Avenue and Coffee Road, which are wider corridors with lower densities of residential areas. This improves constructability, reduces maintenance of traffic requirements, and reduces risks of higher costs associated with additional utility relocation in space-constrained areas and surface restoration. Many of these factors support a faster rate of production during construction for Route Alternative M1 than the other route alternatives. Route Alternative M1 requires fewer easements, and traverses no near-term planned regional transportation projects. The route alternative is also anticipated to have less public impacts and stakeholder challenges than the other route alternatives. Considering economic and non-economic evaluation criteria, Route Alternative M1 is the preferred route to supply Waukesha with a new, sustainable water supply from Milwaukee.

2.1.8 Pipeline Route

Considering economic and non-economic evaluation criteria, Route Alternative M1 is the preferred route to supply Waukesha with a new, sustainable Lake Michigan water supply from Milwaukee. The route for the Water Supply and BPS Discharge Pipelines are shown in **Figure 2-4**.

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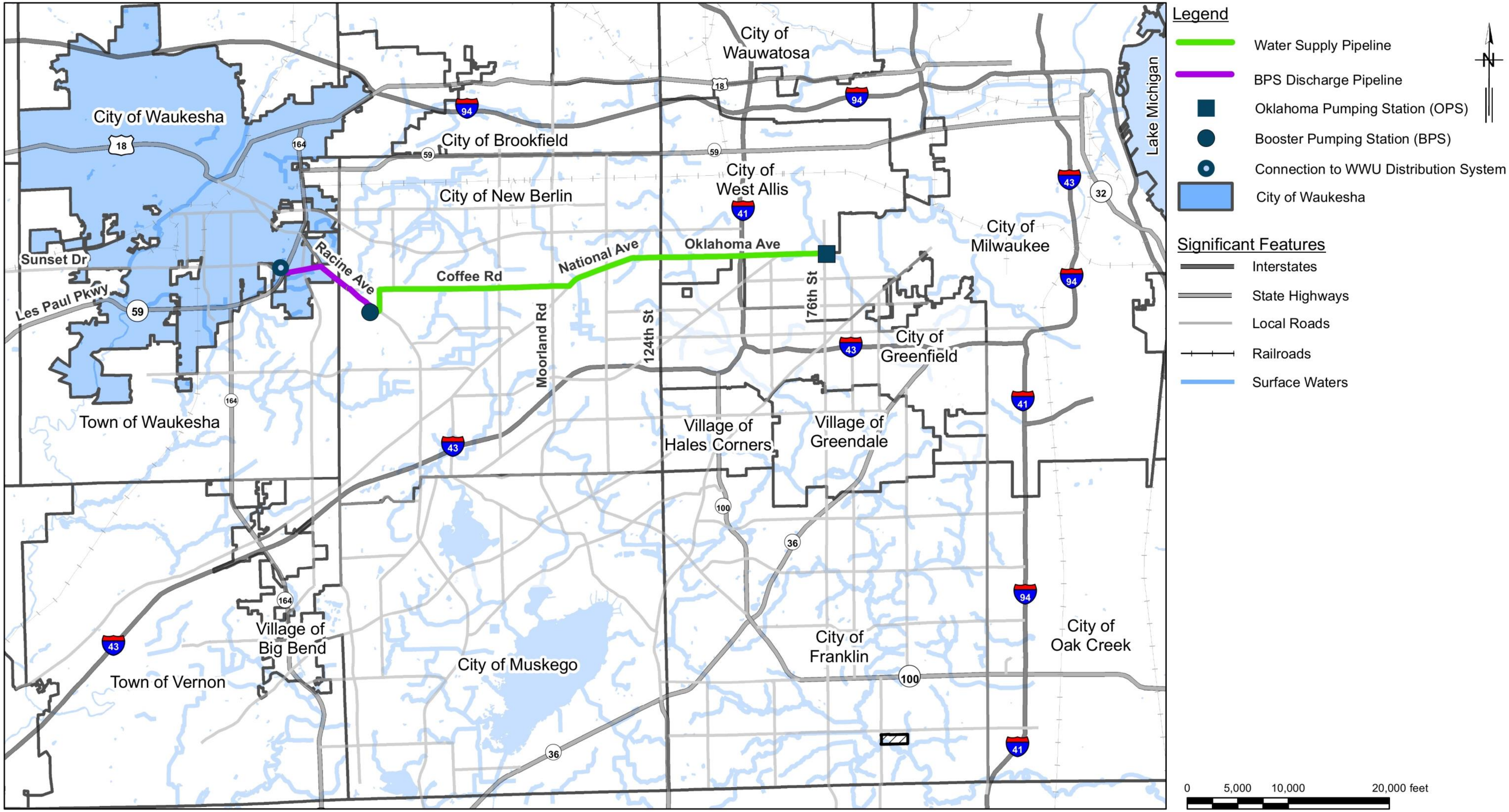


Figure 2-4 BPS Discharge and Water Supply Pipeline Route and Facilities

2.2 Field Investigations

Field investigations were performed to support design along the pipelines, including site survey, geotechnical soil borings, contaminated materials investigations, delineating wetlands and waterways, and investigations for cultural resources, endangered resources, and agricultural resources. These investigations are described within this subsection.

Site Survey: The site survey was conducted within the selected corridors and proposed permanent easements along the pipelines. The utility and topographic survey data was used in the design of the horizontal and vertical alignments.

Geotechnical: The geotechnical field investigations were conducted and consisted of soil borings at increments of 1,000 feet to a minimum depth equivalent to two pipeline diameters below the anticipated pipeline invert elevations. Additional borings were taken at the beginning and ending points of select special crossings. The investigations provided information on the suitability of soils for pipeline appurtenances and structures that were incorporated in the design. Geotechnical field investigation tasks include the following items:

- Standard Penetration Test (SPT) borings drilled to 25-feet below grade (or shallower where bedrock is encountered) and a temporary piezometer and in-situ falling head permeability test every mile, sealed with bentonite if conditions require and plugged with grout.
- Pavement borings at approximately one-mile increments to determine thickness of pavement and subgrade.
- Seasonal high groundwater level at approximately one-mile increments.
- Soil environmental parameter analysis for corrosion control design at approximately 2,000-foot intervals, consisting of sulfate, chloride, pH, redox potential and conductivity.
- Compaction testing on suitable soils to be used for trench backfill.

Findings from the geotechnical field investigations were reviewed and pipeline design was coordinated with the findings from the geotechnical investigations. Geotechnical reports will be made available to the contractors for their reference during construction.

Contaminated Materials: Contaminated materials investigations were completed in conjunction with the geotechnical field work. Phase II Environmental investigations were performed along the pipeline alignments to identify the extent of impacts from known or likely sources of contamination that could affect the design, handling, disposal, Program schedule, or any other aspect needed for due diligence supported by soil and groundwater samples collected during geotechnical investigations. The drawings and specifications were developed to delineate specific handling and disposal requirements based on findings from these investigations as required by WDNR. Phase II Environmental Reports will be made available to the contractor for their reference during construction.

Wetlands and Waterways: Field investigations for wetlands and waterways were conducted along the pipelines to confirm findings from the desktop analyses. Wetland delineations were performed to verify mapped and photo interpreted wetlands along the corridors of the pipelines and within proposed permanent easements. The horizontal alignments were further developed in design to avoid wetland impacts to the extent feasible as described in the Wetland and Waterway Impact Permit Application submitted to WDNR in June 2019.

Endangered Resources: Field investigations for endangered resources were conducted along the pipelines to confirm findings from desktop analyses. The presence of endangered resources in proximity to the pipelines dictated certain requirements which have been incorporated into the Program design.

Cultural Resources: A complete literature and archives search was conducted, including a search of the Wisconsin Historic Preservation Database (WHPD), for the pipelines and facilities, and the Phase I archaeological survey for the routes, including some routes or segments of routes that are no longer part of the Program. The literature and archives research noted a number of historic sites and cemeteries that were once in the various proposed routes.

As the Phase I survey progressed, the majority of the identified historical structures along the studied Program routes were determined to not be impacted, including many that were determined to no longer exist but were not deleted from the WHPD. The Phase I survey identified five archaeological sites, one burial site, two cemeteries, and one potentially historic farmstead that are in the area of the Program routes.

As the development of the horizontal alignments for the pipelines progressed, and as a result of the Phase I archeological survey and Phase I+ survey, it was determined that one of the five identified archaeological sites will be in the vicinity of the Program construction. The construction limits of the work in the vicinity of the identified are outside the boundaries of the identified site, and the construction in the area of the identified site will be completed under the supervision of the Program Archaeologist. Descriptions of the Program sites and construction activities were sent to the Wisconsin State Historic Preservation Office (SHPO) for review. Representatives from SHPO will determine if any additional efforts will be required during construction around these sites.

Agricultural Resources: An agricultural resources impact assessment is an item required by the Public Service Commission (PSC) and the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP) in a construction project. The assessment is comprised of the anticipated impacts to agricultural resources, where fewer impacts are more preferable. An agricultural resources desktop assessment was conducted via review of locations of agricultural lands, quantity of agricultural lands, and types of agricultural lands using the Waukesha County Open Data Portal Website, Milwaukee County Land information Office Geospatial data, the USDA Organic Integrity Database, and the Organic Agriculture in Wisconsin 2017 Status Report and 2015 Status Report. For compliance with DATCP regulations, the Program submitted an Agricultural Impact Notice to DATCP in August 2018 to provide information for the Agricultural Impact Statement. In February 2019, DATCP determined that an Agricultural Impact statement will not be required for the Program.

2.3 Utility Coordination

Utility coordination was completed as part of design. Known utilities within corridors and proposed permanent easements of the pipelines are summarized in **Table 2-4**.

Table 2-4 Utility Source Descriptions

Utility	Description
ANR Pipeline	Gas
AT&T Distribution	Telecommunications/Fiber Optic
AT&T Transmission	Telecommunications/Fiber Optic
City of Greenfield	Sanitary and storm
City of Milwaukee	Sanitary, storm, traffic signals, and water
City of New Berlin	Sanitary, storm, and water
City of Waukesha	Sanitary, storm, and water

Utility	Description
City of West Allis	Sanitary, storm, and water
Level 3 Communications	Telecommunications/Fiber Optic
Midwest Fiber Network	Telecommunications/Fiber Optic
Milwaukee County DPW	Traffic signals
Milwaukee Metropolitan Sewerage District	Sanitary and landfill gas
Sprint Nextel	Telecommunications/Fiber Optic
TDS Metrocom	Telecommunications/Fiber Optic
TesInc	Telecommunications/Fiber Optic
Time Warner Cable	Telecommunications/Fiber Optic
Waukesha County DPW	Traffic signals
We Energies	Electric and gas
West Shore Pipe Line	Petroleum
Windstream	Telecommunications/Fiber Optic
WisDOT	Traffic signals

A standard utility coordination process was followed for the pipelines within the right-of-way corridors and proposed permanent easements to identify the presence and locations of existing utilities. The process is summarized below.

1. A planning ticket, which is a form to request as-built information from utilities, was submitted to the third party utility communication firm, Diggers Hotline. A list of utility companies was received that may have utilities in proximity to the pipeline.
2. Route location maps and utility information requests were sent to the utilities listed on the planning ticket from Step 1, by Diggers Hotline, to supply as-built drawing information of the respective utility. The information is stored in a Program information database and logged to confirm required utilities along the pipelines have been properly identified. If these utilities did not reply, they were re-contacted.
3. In the development of the drawings, general locations were documented from Step 2 and merged with utility information received from the site survey.
4. 60% plans were shared with the utility companies and municipalities with a request to review their utilities on the drawings and meetings were held with the following municipalities and utilities to review the proposed alignments of the pipelines. The design was updated as necessary to coordinate with existing utilities based on feedback from the following meetings:
   - City of Greenfield
   - City of Milwaukee
   - City of New Berlin
   - City of Waukesha
   - City of West Allis
   - Town of Waukesha
   - Milwaukee County
   - Waukesha County
   - We Energies
   - Wisconsin Department of Transportation
5. Potholing was performed by excavating a small hole via a vacuum truck to obtain northings, eastings, and elevations of critical vertical crossings identified in Step 4, and the vertical alignment was updated as necessary. Potholing was utilized during design where the pipeline is crossing utilities without manholes, vaults, or any structure that can be utilized to interpret the given utility's vertical alignment.

SECTION 3 Steady State Hydraulics

Steady state hydraulics were used to determine pipe size, pipe pressure class, restrained joints, pressure test requirements, and support the design of the facilities as described the following subsections.

3.1 Water Demand and Design Capacities

Flow rates were developed based on the Compact Council's Final Decision, which was based on a buildout population of Waukesha, and portions of the Town of Waukesha and the City of Pewaukee of 76,330 for 2050 from Southeast Wisconsin Regional Planning Commission (SEWRPC) estimates. Flows through the water supply system are anticipated to reflect Waukesha's water demand as follows:

- **Static Conditions:** **Static conditions (no flow)** was considered in the hydraulic analysis.
- **Minimum Hour Demand:** The minimum hour demand is anticipated to be **1.2 million gallons per day (MGD)**, which was calculated based on the minimum day demand observed in Waukesha from January 2007 through December 2016 multiplied by the minimum peaking factor observed of 0.4.
- **Initial Average Day Demand:** The initial average day demand (ADD) will be approximately **6.6 MGD**, which is the median water demand observed in Waukesha from January 2007 through December 2016.
- **Initial Peak Hour Demand:** The initial peak hour demand (PHD) will be **15.75 MGD** during a year where the ADD is 6.6 MGD.
- **Approved Average Day Demand**: The ADD is anticipated to reach an ultimate value of **8.2 MGD** at buildout (2050), which is the ADD approved by the Compact Council
- **Approved Maximum Day Demand:** The maximum day demand (MDD) is anticipated to reach an ultimate value of **13.6 MGD** at buildout (2050).
- **Approved Peak Hour Demand:** The PHD is anticipated to reach an ultimate value of **19.0 MGD**

With the above water demand, the design capacities have been determined as follows:

- **Water Supply Pipeline:** **15.1 MGD**, which is equivalent to the firm capacity of the OPS determined in coordination with MWW based on MWW's operational preferences to supply sufficient demand to the reservoirs when periods of maintenance are needed which limit the hours of operation.
- **BPS:** **15.75 MGD**, which is equivalent to Waukesha's existing PHD. The BPS firm capacity can be increased in the future with larger capacity pumps to meet the projected maximum hour demand.
- **BPS Discharge Pipeline:** **19.0 MGD** to accommodate future BPS expansion to the approved PHD.

- **WSCB:** **19.0 MGD** to accommodate future BPS expansion to the approved PHD.

3.2 Roughness Coefficients

The Hazen-Williams formula is typically used to hydraulically model full-pipe flow, where Hazen-Williams Roughness Coefficient (referred to as "C") accounts for major friction losses. The Hazen-Williams formula can be expressed as:

$$Q = 1.318 C R_h^{0.63} S^{0.54} A$$

in which Q is flow rate, A is conveyance area, S is the slope of the hydraulic grade line (HGL), and R_h is hydraulic radius (calculated as A divided by wetted perimeter, P_w). Methods using the Hazen-Williams formula typically use a constant value for C based on the material or age of a given pipe. The Hazen-Williams formula was used for accounting for major head losses along the water supply system pipelines and facilities.

3.2.1 New and Aged Pipe

Pipeline age was evaluated to project the increase in major head losses over a 100-year useful life. Regulations and guidance documents provide a recommended value or range of values for C. Although values for C vary based on pipeline material, pipeline age, and the type of fluid being conveyed, the regulation and guidance documents and manuals of practice do not distinguish between pipe age and material. Roughness coefficients for water mains provided by regulations and guidance documents and manuals of practice include the following items.

- **Ten States Standards:** Recommended Standards for Water Works, 2012 Edition (Ten States Standards).
- **WDNR:** Requirements for the Operation and Design of Community Water Systems, Wisconsin Department of Natural Resources Chapter (WDNR).
- **WWU:** Specifications for Water Main and Service Lateral materials and the Installation of Water Main and Appurtenances for Waukesha Water Utility, 2014 (WWU Specifications).

C values provided by regulations and guidance documents and manuals of practice were compared to flow test data for pipes after years of service. A study performed by the Ductile Iron Pipe Research Association (DIPRA) titled *Cement-Mortar Linings for Ductile Iron Pipe* dated March 2017 summarized the flow testing results performed on cement-mortar lined ductile iron pipe (DIP). The pipes tested were water mains located in 20 cities across the United States. The water mains ranged in nominal diameter from six- to 36-inches and were in service from five- to 77-years at the time of flow testing. **Figure 3-1** shows the flow test results overlaid upon C values provided by regulations, guidance documents, and manuals of practice. A trend line of flow test data as a function of the power of pipeline age is

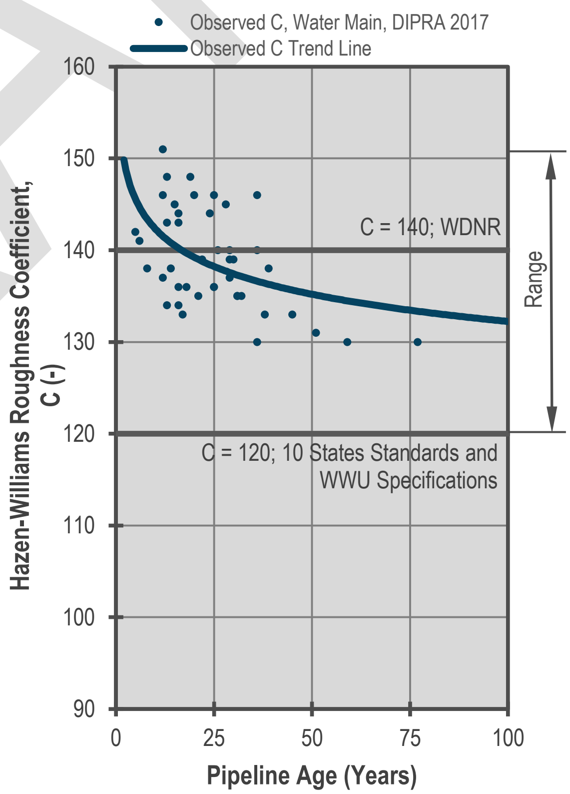


Figure 3-1 Hazen-Williams Roughness Coefficient Analysis with Pipeline Age

overlaid upon the figure. As shown, flow testing data indicate a new pipeline could have C values as high as 150, whereas regulations and guidance documents recommend a range between C = 120 and 140. The hydraulic analysis should consider the full range of operating conditions anticipated for the purpose of sizing the pipeline and pumping facilities. Thus, C values of 120 and 150 have been used to characterize major head losses along the pipelines and facilities.

3.2.2 Scaled Pipe

Water producers in the Midwest have reported lower C values (just below C = 100) in some cases due to scaling and biofilms that develop on pipe surfaces. A C value of 95 (C = 95) was used as a secondary design condition to confirm the pipeline wall thicknesses and restrained joint lengths would be sufficient to withstand operational pressures that could result from conveying the design capacity through scaled pipe typical to that observed in the region.

3.3 Assumptions and Criteria

Assumptions and criteria have been used to support the hydraulic design as follows:

- **Connections to MWW Distribution System:**
  - The water supply system will connect to MWW's Distribution System on Oklahoma Avenue east of Honey Creek.
  - MWW will be capable of conveying the firm capacity of the OPS, which has been confirmed with MWW.
- **OPS:**
  - The firm capacity of the OPS will be 15.1 MGD as determined in coordination with MWW.
  - The OPS will be located southeast of the intersection of 76th Street and Oklahoma Avenue.
- **Water Supply and BPS Discharge Pipelines:**
  - The minimum steady state design pressure will be 35 psi which exceeds the minimum allowable steady state pressure of 20 psi per the WDNR, Subchapter NR 811.70 – Water Main Design and PSC, Subchapter VIII – Operating Requirements, PSC 185.82 – Pressure Standards.
  - The maximum steady state design pressure will be 225 psi. This will eliminate the need for using a pipe with pressure class above 250 psi. Normal operating pressures in excess of 250 psi require thicker pipe walls and non-standard, more robust valves, which would increase cost and complexity of design.
  - A maximum velocity of seven feet per second (fps) is desirable for pipeline sizing of the pipeline to maintain head losses within reasonable tolerance and conserve energy during pumping.
  - The Water Supply Pipeline will have a design capacity of 15.1 MGD.
  - The BPS Discharge Pipeline will have a design capacity of 19.0 MGD.
  - The pipelines will be constructed of DIP with major head losses due to friction and hydraulic turbulence representative of the C values in **Table 3-1.** HDD segments comprised of high density polyethylene (HDPE) pipe will impose head loss within the range of C values in **Table 3-1**.

Table 3-1 Roughness Coefficients

Item	Hazen-Williams C
Hydraulic Condition	Pressurized
New	C = 150
Aged	C = 120

- Fittings and valves will induce minor head losses calculated as $K\frac{V^2}{2g}$ with K values as shown in **Table 3-2**.

Table 3-2 Minor Head Loss Friction Factors

Bends (Degrees)					
11.25	22.5	30	45	60	90
0.05	0.075	0.10	0.20	0.25	0.30
Other Fittings					
Reducer	Tee, Run	Tee, Branch	Entrance	Exit	Open Butterfly Valve
0.20	0.30	0.60	0.50	1.00	0.50

- **BPS, Storage, and Chemical Facilities:**
  - The water reservoirs and BPS will be located on Parcel NBC 1224994 owned by the Waukesha County Department of Parks and Land Use at the southwest quadrant of Racine Avenue and Swartz Road.
  - The BPS will operate to meet the diurnal demand of Waukesha.
  - The BPS will be expanded in the future to a firm capacity of 19.0 MGD.
  - The BPS will have yard piping capable of bypassing the BPS pumps to allow maintenance on the BPS pumps while still allowing water conveyance to WWU. This hydraulic condition has been called the bypass condition and has been used as a secondary design criterion.
  - The water reservoirs and BPS operational configuration will be as follows: Flow will be conveyed from the OPS to a pressure sustaining valve (PSV) upstream of an air break in the water reservoirs. The PSV will maintain a minimum pressure of 35 psi in the Water Supply Pipeline upstream of the water reservoirs. The BPS will draw from the water reservoirs and provide the head necessary to supply WWU's Distribution System to an elevation set point of 1,120 feet.

- **WSCB:**
  - The WSCB will be located on Parcel WAKC 1349999 owned by WWU on the northwest quadrant of the intersection of Sunset Drive and Les Paul Parkway.
  - The WSCB will house pressure sustaining and reducing valves (PSRVs). The PSRVs will reduce pressures in the BPS Discharge Pipeline to within a desirable range for WWU's distribution system and sustain a minimum upstream pressure of 35 psi on the Water Supply Pipeline.

- **Connections to WWU Distribution System:**
  - The water supply system will connect to WWU's Distribution System near the intersection of Sunset Drive and Les Paul Parkway at a 24-inch trunk main.

3.4 Model Development

A steady state hydraulic model was developed using alignment data and locations of pumps, valves, and fittings for the facilities and pipelines, exported from the Program drawings, to determine head loss from the pre-90% progress set. Hydraulics were modeled starting from the downstream beginning at the OPS.

3.5 Pipeline Size

3.5.1 Water Supply Pipeline

Three pipeline nominal diameters were evaluated for the Water Supply Pipeline, including 24-, 30-, and 36-inches, based on maintaining pressures within an acceptable range of between 35 and 225 psi and at velocities of less than seven fps. The pipelines were sized for the maximum normal operating pressures at C = 120 to provide pipelines capable of conveying the range of heads anticipated throughout the 100-year useful life. **Table 3-3** shows maximum steady state pressures and velocities along the Water Supply Pipeline per diameter.

Table 3-3 Water Supply Pipeline Sizing

Nominal Diameter (in)	Inside Diameter (in)	Velocity (fps)	Maximum Pressure (psi)
24	24.81	6.97	**297**
30	30.91	4.49	201
36	37.11	3.12	172

Notes:
1. Cells shaded **red** are greater than the maximum steady state design pressure criterion of 225 psi or the maximum velocity of seven fps.

As shown, a 24-inch nominal diameter would result in pressures in excess of the maximum steady state design pressure of 225 psi. In consideration of the Program's vision for a 100-year useful life, a 24-inch pipeline would be insufficient. Both 30- and 36-inch nominal diameter pipelines would be capable of conveying the design capacity with acceptable pressures and velocities. A 36-inch nominal diameter, however, would result in a higher capital investment with limited benefit. As such, a 30-inch nominal diameter pipe is the preferred size for the Water Supply Pipeline to satisfy the demand conditions approved by the Compact Council and pursue the Program's vision for infrastructure with a 100-year useful life.

3.5.2 BPS Discharge Pipeline

Three pipeline nominal diameters were evaluated for the BPS Discharge Pipeline, including 24-, 30-, and 36-inches, based on maintaining pressures and velocities within design criteria. The pipeline was sized for the maximum normal operating pressures at C = 120 to provide a pipeline capable of conveying the range of heads and flows anticipated throughout the 100-year useful life. A 24-inch diameter pipeline would result in velocities in excess of seven fps and, therefore, a 24-inch pipeline is not preferred. Both 30- and 36-inch nominal diameter pipelines result in acceptable hydraulic conditions, however, the 36-inch pipeline is able to maintain velocities below five fps, which is more desirable for the higher flow rates anticipated through the BPS Discharge Pipeline necessary to accommodate Waukesha's PHD from the BPS at ultimate buildout. As such, a 36-inch nominal diameter pipe was selected for the BPS Discharge Pipeline to better accommodate the anticipated range in flows.

3.6 Hydraulic Grade Lines and Normal Operating Pressures

Steady state hydraulic conditions along the water supply system are summarized with HGLs for the purposes of defining pipeline test pressures, pressure class, and restrained joint design in **Figure 3-2**. The HGLs are shown for new (C = 150), aged (C = 120), and scaled conditions (C = 95) for normal operations. Bypass operations is also shown for aged conditions.

3.7 Pipeline Test Pressures

Pipeline test pressures were determined in accordance with American Water Works Association (AWWA) C600 Installation of Ductile Iron Pipe. AWWA C600, Section 5.2 Hydrostatic Testing recommends:

1. The test pressure to be not less than 1.25 times the stated working pressure of the pipeline measured at the highest centerline elevation and not less than 1.5 times the stated working pressure at the lowest elevation.
2. The test pressure to be not greater than the thrust restraint design pressure.

The resulting test pressure for the BPS Discharge Pipeline is equivalent to an HGL of 1,260 feet. For the Water Supply Pipeline, Item 2 dictates the test pressure, which results in an HGL of 1,300 feet, or the test pressure that would result in a maximum pressure equal to the thrust restrained design pressure of 250 psi. The test pressures are shown in **Figure 3-2** in **blue**.

3.8 Pipeline Pressure Class

WWU determined that the Water Supply and BPS Discharge Pipelines will be designed with pipe rated for 250 psi for the portions of the pipeline that will be owned and operated by WWU. MWW determined that the portion of the Water Supply Pipeline owned and operated by MWW will be Special Thickness Class 55 for DIP segments. These pressure classes were confirmed by comparing the test pressures and the isotropic pressure lines shown on **Figure 3-2**. The isotropic pressure lines are shown for +150 psi (350 feet), +200 psi (460 feet), and +250 psi (580 feet) increments above the pipeline centerline elevation from the pre-90% drawing progress set. The pressure classes are shown near the top of **Figure 3-2** in **blue**. The pipelines were designed with the following pipe pressure classes for DIP in open-cut and jack and bored segments and HDPE pipe in HDD segments:

- **DIP:** Pressure Class 250 (WWU-owned) and Special Thickness Class 55 (MWW-owned)
- **HDPE Pipe:** Iron Pipe Size (IPS) Dimension Ratio (DR) 9

3.9 Pipeline Restrained Joints

Restrained joints were designed to balance thrust forces exerted by the flow at fittings and valves in accordance with AWWA M41 and as follows. The restrained joints were valued engineered for the specific depth of cover and pressure class shown in **Figure 3-2** at each fitting and valve utilizing a 1.5 factor of safety and friction resistance accounting for polyethylene encasement. The unit bearing resistance, or the resistance of the soil to resist movement due to thrust forces, was conservatively neglected to account for the potential reduction in resistance due to work by others near the pipelines, such as new utilities or similar below grade construction.

3.10 Flow Velocities and Special Coatings

At velocities in excess of 15 fps, friction forces from flowing water can damage the cement-mortar lining of DIP. Velocities were evaluated at the design capacity to identify whether any DIP sections would require special coatings to protect against friction forces exerted by high velocities. No sections of the pipelines are anticipated to have velocities in excess of 15 fps during normal operations. Thus, a special DIP coating is not required.

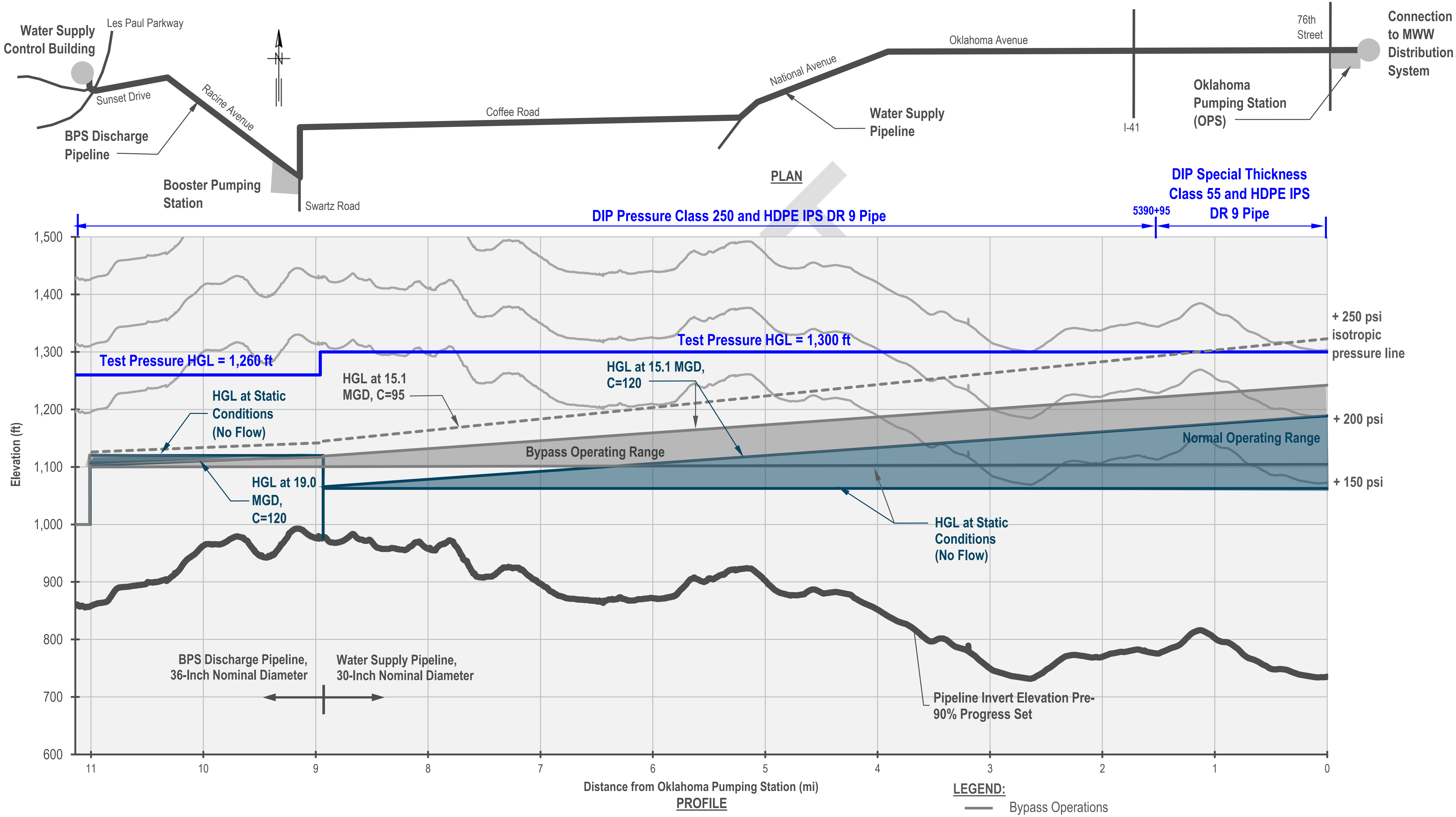


Figure 3-2 Hydraulic Grade Lines (HGL), Test Pressure, and Pipe Pressure Class

SECTION 4 Design Philosophy, Pipelines

The pipelines will be comprised of DIP, DIP in steel casings, and HDPE pipe along HDD segments. The following subsections describes the approach used in designing the pipelines, including pipe materials, pipe joints and gaskets, horizontal and vertical alignment, pipeline appurtenances, and cathodic protection.

4.1 Pipe Materials

Pipeline materials were evaluated, including DIP, pre-stressed concrete cylinder pipe (PCCP), steel pipe, polyvinyl chloride (PVC) pipe, and HDPE pipe. The Program determined that the pipe material for the pipeline will be DIP for segments constructed via open-cut construction and trenchless construction via jacking and boring. The decision was made for the following key reasons:

- WWU staff are familiar with operating and maintaining DIP.
- For the same nominal diameter, DIP has a larger inner diameter than HDPE and PVC pipe shown in **Table 4-1**. The larger inner diameter requires less head to convey flow from the OPS and BPS.

Table 4-1 Nominal 30 and 36-inch DIP, HDPE Pipe, and PVC Pipe Geometry for 250 psi or Maximum Allowable Working Pressure

DIP (inch)(1)			HDPE Pipe (inch)(3)			PVC Pipe (inch)(4)		
OD	t(2)	ID	OD	t	ID	OD	t	ID
Nominal 30-Inch								
32.00	0.510	30.98	30.00	3.54	22.93	32.00	1.89	28.23
Nominal 36-Inch								
38.30	0.595	37.11	36.00	4.24	27.52	38.30	1.94	34.43

Notes:
1. Dimensions sourced from United States Pipe and Foundry Company, TYTON JOINT Pipe.
2. Includes 1/8-inch cement-mortar lining thickness.
3. Dimensions sourced from Performance Pipe, 4710 IPS DR 9 (250 psi) for 30- and 36-inch pipe based on an average t rounded to the nearest hundredths of an inch.
4. Dimensions sourced from JM Eagle, BIG BLUE, DR 18 (235 psi) for 30-inch, and DR 21 (200 psi) for 36-inch based on an average t rounded to the nearest hundredths of an inch.

- Quotes were received from pipe manufacturers shown in **Table 4-2**. DIP is the most economic material for the pipe diameter and rated working pressures for the Program.

Table 4-2 Material Costs For Pipe Rated for 250 psi or Maximum Allowable Working Pressure

DIP(1)	HDPE Pipe(2)	PVC Pipe(3)	PCCP(4)	Steel Pipe(5)
Nominal 30-Inch Pipe				
$98/LF	$190LF	$112/LF	$126/LF	$131/LF
Nominal 36-Inch Pipe				
$133/LF	$273/LF	$145/LF	$145/LF	$157/LF

Notes:
1. Quote provided by United States Pipe and Foundry Co, American Cast Iron Pipe, and McWane Ductile, 30- and 36-inch nominal diameter push-on joint pipe, pressure class 250, June 2018.
2. Quote provided by Core & Main, 30-inch and 36-inch nominal diameter fusible joint pipe, IPS DR 9 (250 psi), October 2018.
3. Quote provided by Core & Main, 30-inch nominal diameter push-on joint pipe, DR 18 (235 psi), and 36-inch nominal diameter push-on joint pipe, DR 21 (200 psi), October 2018.
4. Quote provided by Thompson Pipe Group, 30- and 36-inch nominal diameter push-on joint pipe, pressure class 250, January 2018.
5. Quote provided by Northwest Pipe Company, 30-and 36-inch nominal diameter push-on joint pipe, ¼-inch thickness, June 2018.

HDPE pipe was selected for use in segments of the pipeline installed with trenchless construction via HDD in areas without suspected soil or groundwater contamination. The use of DIP for HDD can damage the integrity of the polyethylene encasement typically installed with DIP, which increases the risk of corrosion and pipe failure. HDD is typically utilized where surface disruption for excavation is either not permitted or not desired for constructability reasons. Therefore, pipeline segments of DIP installed via HDD would have a higher risk of failure than the rest of the pipeline and have less means to access the pipe for maintenance and repair. HDPE pipe is jointed with smooth, heat-induced fusion welded joints that are inherently restrained and ideal for HDD applications. HDPE pipe is also inert to corrosion, reducing the risk of maintenance of repair along HDD segments than DIP.

4.2 Pipe Joints and Gaskets

Pipe joints were designed for the selected pipe materials and sizes to accommodate the pipelines and appurtenances, provide proper restraint, and allow for adequate deflection depending upon the installation condition. Push-on or mechanical joints will be provided for buried and encased DIP, and DIP in steel casings. HDPE pipe will be provided with fusion welded joints. Exposed piping in vaults will be provided with screwed joints for sizes less than three inches and flanged joints for sizes three inches and greater. Buried and exposed stainless steel vent riser pipes will be welded.

The specifications were developed to require DIP gaskets in accordance with AWWA C111 Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings. Manufacturers have indicated this requirement will lead them to provide styrene butadiene gaskets (SBR) where special gaskets are not required due to SBR being more cost-effective. Special gaskets, including Nitrile and Viton® gaskets, were specified along select pipeline reaches. Nitrile gaskets were specified at petroleum pipeline crossings owned by the West Shore Pipe Line Company in accordance with West Shore Pipe Line Company crossings requirements for 125 linear feet, centered on the crossing. In pipeline reaches with suspected soil or groundwater contamination, the type of gasket was selected based on data obtained from field investigations and as recommended by pipe manufacturers. Pipeline reaches through soil or groundwater with suspected polycyclic aromatic hydrocarbons (PAHs) were specified with Viton® gaskets through the suspected contamination and extending 50-feet beyond the suspected contamination, whereas pipeline reaches through suspected soil or groundwater contamination with no suspected PAHs were specified with Nitrile gaskets through the suspected contamination and extending 50-feet beyond the suspected contamination.

4.3 Horizontal and Vertical Alignment

The horizontal and vertical alignments have been developed based on the route shown in **Figure 2-4**. The plan and profiles will be submitted to WDNR as part of the 90% Contract Documents for the Program after a Certificate of Authority is received from the PSC. Construction methods, including open-cut construction and trenchless construction, were utilized to develop the horizontal and vertical alignments. The construction methods described in the following subsections are based on pipeline constructed of DIP with HDPE pipe used for segments requiring trenchless construction via HDD.

4.3.1 Open-Cut Construction

Open-cut construction consists of excavating a trench, laying the pipe, and backfilling the pipe to finished grade. This method requires surface restoration in the form of pavement or landscape restoration for the disturbed surface above the trench. The typical sections shown in **Figure 4-1** for open-cut construction beneath and beyond pavement were developed per applicable municipal and state standards.

It is less expensive to construct pipelines beyond pavement, as it eliminates the cost for pavement restoration. Open-cut construction beyond pavement allows the use of common fill, which is typically readily obtained from excavated spoils and less expensive than flowable or select fill required beneath pavement. The pipeline was aligned beyond pavement where feasible.

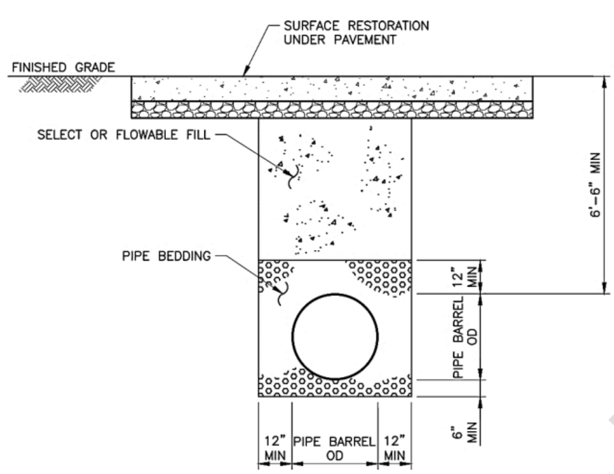


Figure 4-1 Pipeline Trench Sections Beneath and Beyond Pavement

Groundwater barriers shown in **Figure 4-2** were placed along open-cut sections of pipelines to mitigate the flow of groundwater (i.e., the French drain effect) that could arise due to pipe bedding and its larger porosity than that of much of the surrounding native soils. For multiple pipelines sharing a common trench, the barriers will be extended across all pipelines and keyed into native soil.

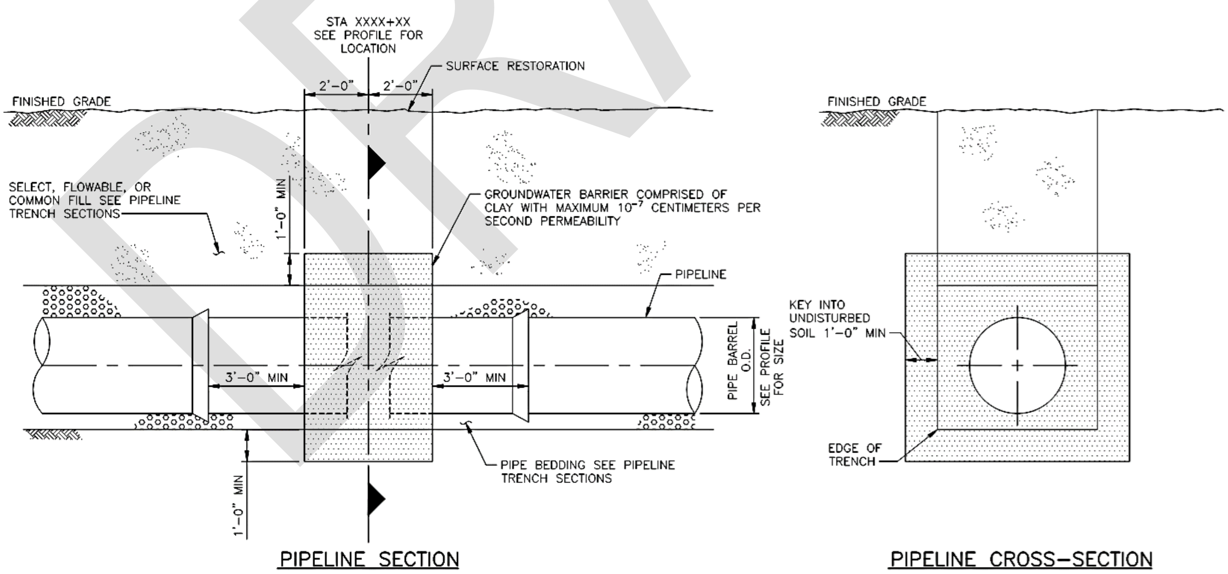


Figure 4-2 Groundwater Barrier Detail

Groundwater barriers were placed along the pipelines as follows:

- At intervals of approximately 1,000 linear feet along the pipeline for pipeline slopes less than 5%.
- At intervals of approximately 500 linear feet along the pipeline for pipeline slopes greater than 5%.
- Either side of suspected soil or groundwater contamination.
- Either side of waterway crossings.

4.3.2 Trenchless Construction

Trenchless construction is typically utilized as a means of mitigating disruption to the surface and minimizing surface restoration requirements along the length of the trenchless installation. Two trenchless construction methods have been used in design, the jack and bore and HDD methods.

Studies have compared costs for open-cut and trenchless construction, and generally indicate that trenchless construction costs vary based on the application, locality, and diameter. Recent bid tabs in Southeast Wisconsin were reviewed to compare costs of open-cut vs trenchless construction via HDD. It was determined that trenchless construction via HDD has higher per linear foot unit cost than open-cut construction beneath pavement in the diameter range required for the pipelines for the Program on average, even when considering surface restoration for open-cut construction. In designing the pipelines, open-cut construction was utilized where feasible. Trenchless construction was considered to mitigate the following:

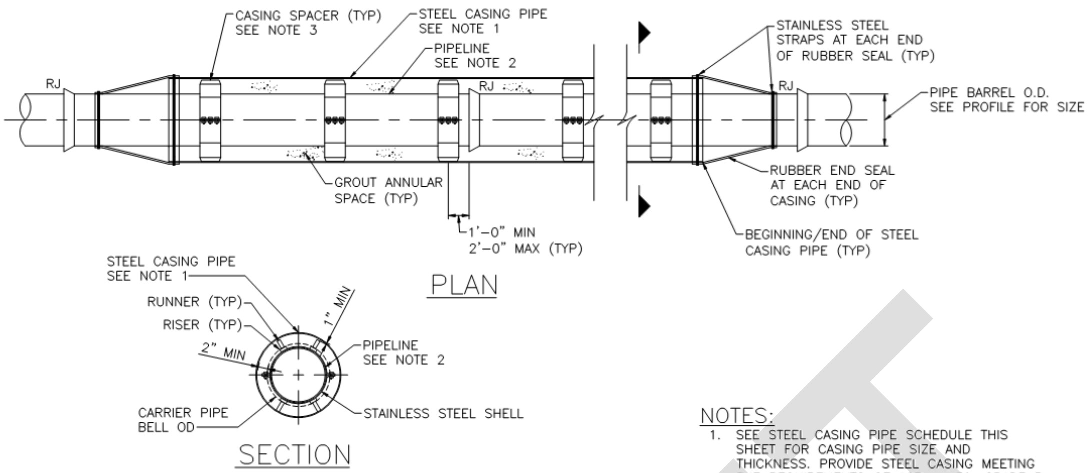
- Impacts to waterways crossing route alternatives.
- Traffic disruption where the pipelines are to be located under major roads, highways, and railroads.

The Program worked with the WDNR in preparation for the Wetland and Waterway Impact Permit Application submitted to WDNR in June 2019. A practicable alternatives analysis was used to demonstrate the required minimization of wetland impacts. Trenchless construction was not considered a practicable alternative to avoid wetlands due to the higher cost required for the construction method.

4.3.2.1 Jack and Bore Method

The pipelines have been designed using the jack and bore method to cross railroad tracks or as a means to mitigate traffic disruption when crossing a major roadway. A plan and section view of the pipelines installed via jacking and boring is shown in **Figure 4-3**. Jack and bored crossings can typically be installed up to 400 feet in length.

The steel casing diameter required to accommodate the pipelines is larger than the diameter range and thickness requirements provided by many authorities having jurisdiction where the pipelines will be located. As such, the thickness of the steel casing was calculated in accordance with AWWA M11 using the Iowa deflection formula for bare pipe with a deflection factor of 5.0%, a modulus of elasticity of 30,000,000 psi, a bedding constant of 0.1, a deflection lag factor of 1.0, and soil loads and live rail and road loads in accordance with AWWA M11. The modulus of soil reaction was conservatively neglected to account for future work done by others near the pipelines, such as new utilities or similar below grade construction, which could sacrifice the soil's structural integrity. The annular space between the pipeline and casing pipe will be grouted in order to mitigate potential groundwater infiltration that could result in corrosion of the pipeline.



STEEL CASING PIPE SCHEDULE		
CARRIER PIPE NOMINAL DIAMETER	STEEL CASING PIPE INSIDE DIAMETER	STEEL WALL THICKNESS ROAD
30"	48"	0.625"
36"	54"	0.625"

NOTES:
1. SEE STEEL CASING PIPE SCHEDULE THIS SHEET FOR CASING PIPE SIZE AND THICKNESS. PROVIDE STEEL CASING MEETING THE REQUIREMENTS OF ASTM A139, GRADE B.
2. PROVIDE CARRIER PIPE WITH RESTRAINED JOINTS (RJ) THROUGHOUT THE LENGTH OF THE STEEL CASING PIPE.
3. INSTALL CASING SPACERS OVER POLYETHYLENE ENCASEMENT AND TRACER WIRE. POLYETHYLENE ENCASEMENT AND TRACER WIRE NOT SHOWN FOR CLARITY.

Figure 4-3 Trenchless Construction via Jack and Bore Method

4.3.2.2 Horizontal Directional Drilling (HDD)

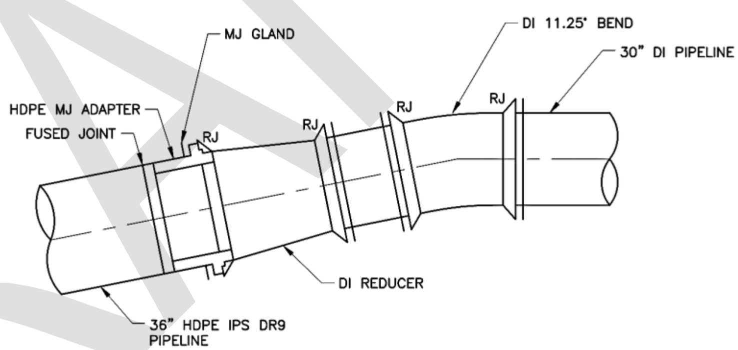


Figure 4-4 DIP to HDPE Pipe Transition

HDD was used for longer trenchless installations beyond that of the jack and bore method, such as that required for waterway crossings. The pipeline design was developed to include construction via HDD comprised of 36-inch HDPE IPS DR 9 pipe. Transitions to HDD will be as shown in **Figure 4-4** for the Water Supply Pipeline; the BPS Discharge Pipeline does not require HDD. The larger HDPE pipe diameter was used to accommodate HDPE pipe's wall thickness, thereby maintaining an inner diameter comparable to DIP. The radius of curvature for HDD segments was designed to account for the limiting radius of curvature of drilling equipment with feedback from HDD contractors.

4.3.3 Minimum Horizontal Separation

The BPS Discharge Pipeline will be located in the same corridor as the Return Flow Pipeline for approximately 2 miles of the alignment and both the Water Supply and BPS Discharge Pipelines will be located within the same corridors as existing sewer or storm mains at various locations. Discussions with the WDNR have indicated the WDNR will classify the Return Flow Pipeline as a sanitary sewer force main. Existing utilities were surveyed and overlaid upon the plan and profile sheets. The horizontal alignments have been developed to satisfy Wisconsin Administration Code NR 811.74, which requires water mains to be laid a minimum of eight-feet horizontally, center to center, or a minimum of three-feet horizontally, wall to wall, from any sanitary sewer main.

4.4 Limits of Construction

4.4.1 Open-Cut Construction

The limits of open-cut construction were quantified to provide a basis for maintenance of traffic requirements and to design limits of construction on the drawings. The limits of open-cut construction for a single pipeline are anticipated to be a maximum of 50-feet wide as described below and as shown in **Figure 4-5**:

- Two-foot wide traffic barrels and a two-foot width between the traffic barrels and dump truck.
- A 10-foot wide dump truck.
- A 12-foot wide excavator above the pipe trench with four-feet on either side to account for tail swing.
- A 10-foot wide staging area for materials.
- Two, 3-feet wide workspace buffers to the limits of construction.

In select areas, the minimum limits of construction for a single pipeline will be set at a minimum of 22-feet wide. The contractor will locate the dump truck longitudinally with the excavator, eliminate the workspace buffers and reduce the traffic barrel width, and stage materials elsewhere. It is anticipated the limits of construction will be larger than the minimum width of 22-feet where pipeline appurtenances are required, such as blow-off assemblies, air valves, and isolation valves. The limits of construction has been increased where the BPS Discharge and Return Flow Pipelines are located in the same corridor. Note that the contract documents will include the limits of construction, not the staging of specific equipment. The contractors will have the autonomy to setup equipment in a manner so as to efficiently and effectively complete the work. The contractor may elect to stage in a different manner than that described in this Report.

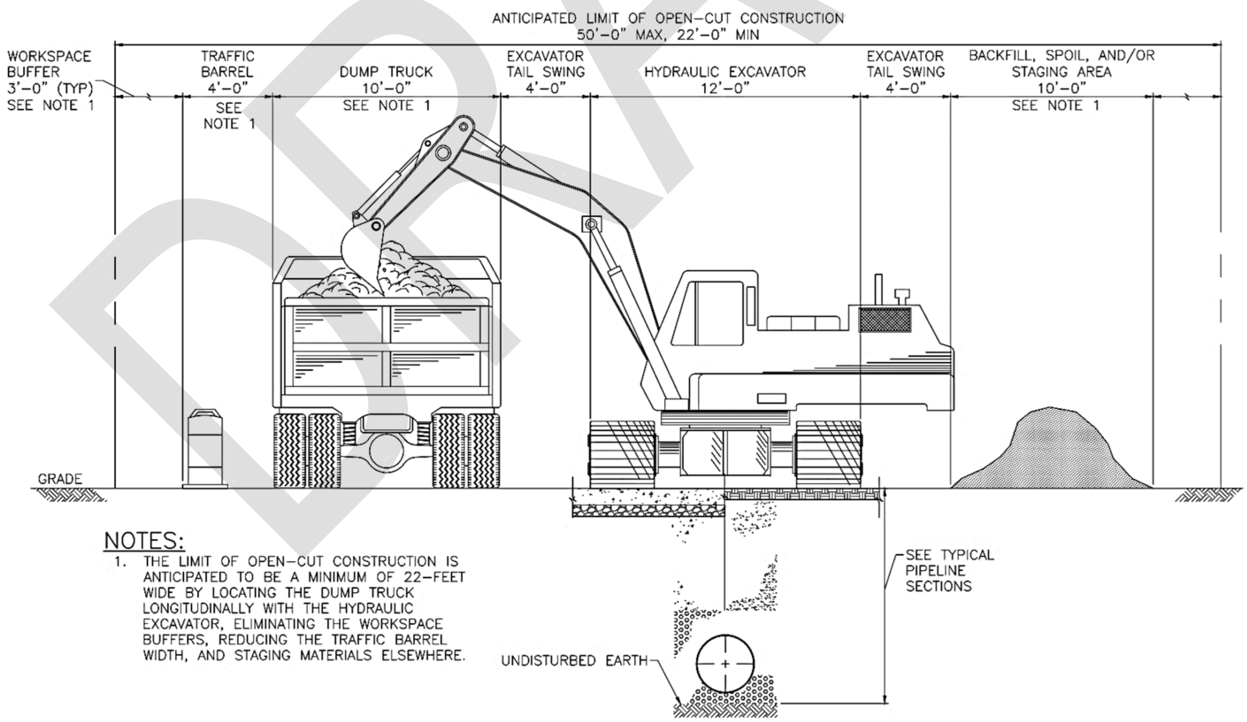


Figure 4-5 Anticipated Limits of Open-Cut Construction

4.4.2 Trenchless Construction

If space within the right-of-way permits, then equipment, pits, and materials used for trenchless construction via the jack and bore method could be staged beyond pavement to reduce maintenance of traffic requirements. If space within the right-of-way beyond pavement is limited, then limits of trenchless construction via the jack and bore method are anticipated to utilize the 22-foot width of a two-lane, two-way road assuming the following equipment and material are staged behind the pits:

- Two-foot wide traffic barrels.
- 20-foot wide working and receiving pits. The jacking pits have been shown on the drawings to assist the contractor in staging during construction.

If space within the right-of-way permits, equipment and materials used for trenchless construction via HDD can be staged beyond pavement to reduce maintenance of traffic requirements. If space within the right-of-way beyond pavement is limited, then the limits of HDD construction for a single pipeline are anticipated to utilize the 22-foot width of a two-lane, two-way road assuming the following as shown in **Figure 4-6**:

- Two-foot wide traffic barrels and a two-foot width between the traffic barrels and HDD rig.
- An eight-foot wide HDD rig.
- A 10-foot wide staging area for materials and equipment supporting HDD operations.

Potential for substantial reduction of the trenchless construction width down to one lane of traffic is limited for the following reasons:

- It is desirable to stage the operator house adjacent to the entry pit so the drilling can be safely observed.
- Additional space is required where pipeline appurtenances are located, such as blow-off assemblies, air valves, and isolation valves that require manholes. Blow-off assemblies and air valves will require outlets routed to the right-of-way beyond pavement.

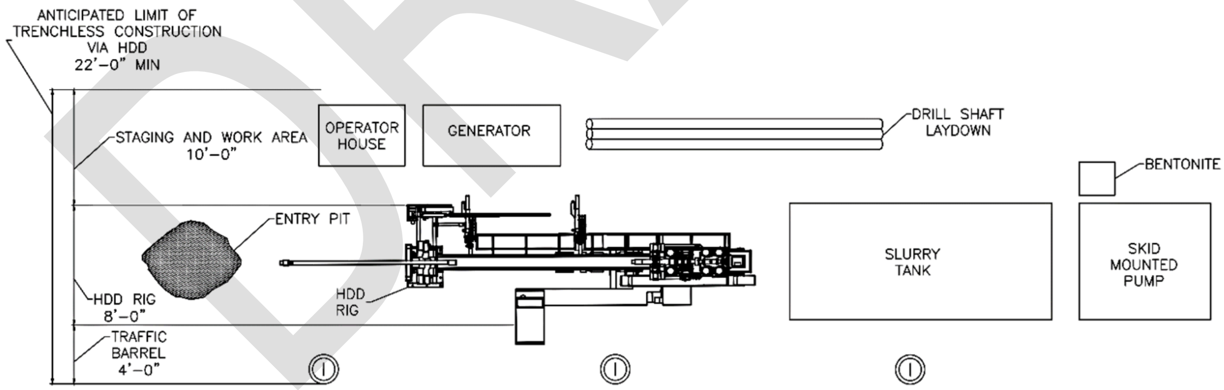


Figure 4-6 Anticipated Limits of Trenchless Construction via HDD

Workspace for HDD construction is required simultaneously on both ends of the trenchless segment. When using HDPE pipe, the pipe joints are typically heat-fused at the surface and strung out for the length of the intended trenchless segment beyond the exit point of the trenchless segment. The specifications were developed to allow the contractor the ability to heat fuse only segments of a given portion of an HDD segment if space constraints exist in the right-of-way.

4.5 Pipeline Appurtenances

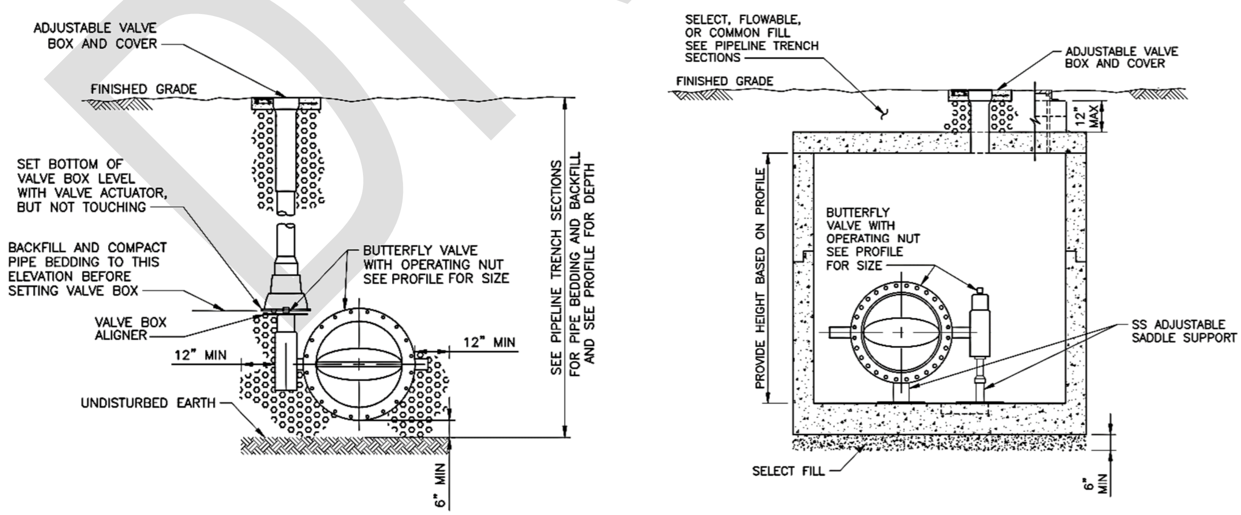
Pipeline appurtenances were designed for the pipelines to provide for ease of maintenance and air management. Key design philosophies for each appurtenance are described in the following subsection for Waukesha's new water supply system. Note that pipeline appurtenances along the MWW-owned portion of the water supply system were designed in coordination with MWW and would be included in a separate engineering report as necessary for the OPS and Station Suction Pipelines.

4.5.1 Isolation Valves

Four types of isolation valves were considered for the pipeline, including butterfly, gate, ball, and plug valves. Ball valves are not generally utilized for isolation valves on water transmission mains and are typically more expensive than gate valves. Plug valves are commonly used in the wastewater industry, but are more expensive than gate valves. Based on the economics, suitability for the application, and product availability, ball and plug valves were determined to be less preferable and were not further evaluated as means of providing isolation for the pipelines.

Butterfly valves and gate valves were further evaluated. Butterfly valves are lighter in weight, more compact in size, require lower operating torque, and are less costly than gate valves. However, gate valves do not have a disc that passes through the flow path and, therefore, induces a lower head loss during operations. A lifecycle cost evaluation was completed and it was determined the monetary savings from lower head loss would not compensate for the higher capital cost of the gate valve. Based on economic and non-economic considerations, it was determined that butterfly valves will be used as a means of isolation for the pipelines.

Isolation valves can be installed in vaults or direct buried with a valve box for the valve operator. Installation of vaults allows for ease of maintenance, but would be susceptible to groundwater infiltration, which would require dewatering to access the valve. Direct buried valves with valve boxes are more cost-effective and are more common for water utilities, but maintenance would require excavation. Isolation valve details were reviewed with WWU. It was determined that isolation valves will be direct buried to reduce capital cost and additional maintenance associated with vaults. Isolation valves in vaults were designed upstream of surface water crossings greater than 15 feet in width in accordance with NR 811.76. Sections of the isolation valve details are shown in **Figure 4-7.**



Section, Buried

Section, In Vault

Figure 4-7 Isolation Valve Details

4.5.2 Blow-Off Assemblies

Pipelines require appurtenances that will provide means to drain the pipelines during startup, routine maintenance, or repairs. Two types of appurtenances were evaluated for draining the pipelines, including blow-off assemblies and flushing hydrants. Blow-off assemblies are typically used for transmission mains as they reduce the potential for unintended use by eliminating above grade components, whereas flushing hydrants, which are commonly used for distribution systems, include a hydrant above grade. Flushing alternatives were reviewed with WWU and it was determined that blow-off assemblies are preferred as it limits the potential for access by outside entities in the communities that the pipelines will be located. Blow-off assembly details developed for the pipeline are shown in **Figure 4-8**.

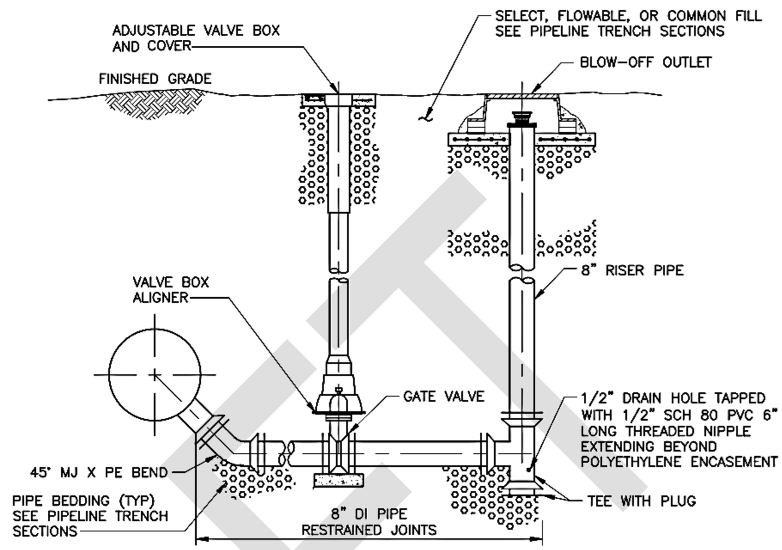


Figure 4-8 Blow-Off Assembly Detail – Section

4.5.3 Air Valves

Hydraulic transients can lead to vacuum conditions that require air to be admitted into the pipelines to protect against pipeline breakage. Air entrainment can reduce capacity, which can lead to lower pumping efficiency and, potentially, air binding of the system. In order to minimize the rise and fall of the pipeline elevations, which could result in additional air valves, the pipeline may need to be buried deeper. This increases the cost of installation through additional cut and fill, but can eliminate the need for additional air valves. The vertical alignment was optimized to balance cut and fill with additional air valves. Air valves were located along the resulting vertical alignments at local high points. Since the pipelines will be comprised of transmission mains where dampening of transient hydraulics in gridded distribution systems would be limited, the pipelines were designed with provisions for automatic air vacuum as well as automatic air release at local high points. Refer to **Section 7** for the method used in sizing the air valves, air valve details, and the size, type, and location of air valves.

4.6 Corrosion Control and Cathodic Protection

Corrosion is a common mechanism that can reduce the service life of any metallic pipe, including DIP. The pipelines were designed per AWWA standards for corrosion protection. Design provisions in excess of AWWA standards were included to provide for a 100-year service life to mitigate the potential for corrosion as follows:

- **Polyethylene Encasement:** AWWA C105 Polyethylene Encasement for Ductile-Iron Pipe Systems requires a single layer of polyethylene encasement to mitigate soil and groundwater-induced corrosion. The pipelines were designed with two layers of polyethylene encasement. The inner layer will consist of V-Bio® Enhanced Polyethylene Encasement, which includes a layer to mitigate biologically-induced corrosion from any soil or groundwater that could have migrated into the annular space between the pipe wall and the encasement during installation. The outer layer will consist of standard polyethylene encasement in accordance with AWWA C105. After installation, both layers will serve to mitigate soil and groundwater-induced corrosion by preventing migration of soil or groundwater to the pipe wall.

- **Galvanic Magnesium Anodes:** The pipelines were designed with buried sacrificial galvanic magnesium anodes based on findings from field investigations from soil borings and coordination with existing utilities that utilize cathodic protection. In the presence of a corrosion mechanisms, magnesium corrodes preferentially to iron. Should the two layers of polyethylene encasement become locally compromised, the magnesium anodes will corrode preferentially to the DIP. Sacrificial anodes are not required per AWWA Standards and are a means of designing additional protection to the pipelines for the 100-year service life. A trench section at a galvanic magnesium anode developed for the pipeline is shown in **Figure 4-9**.

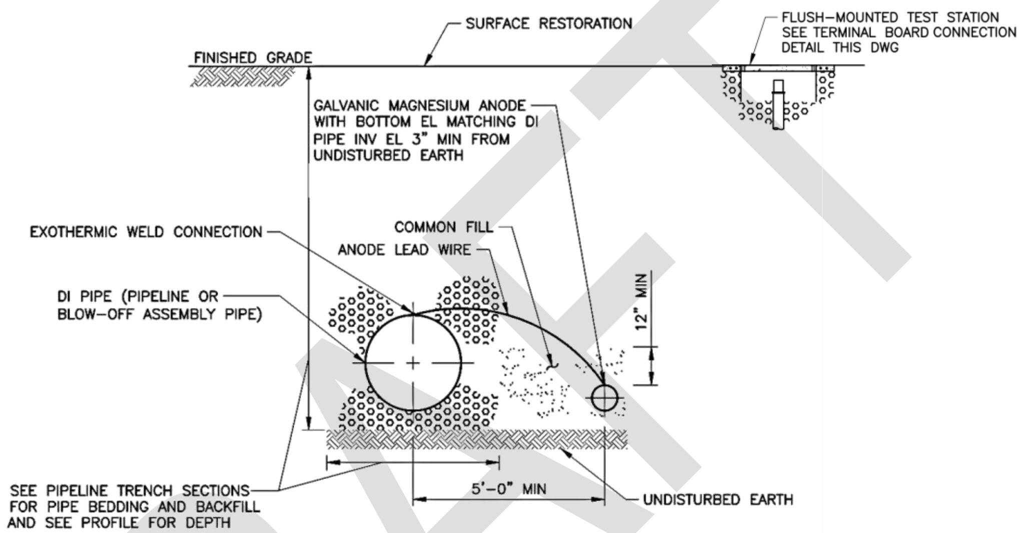


Figure 4-9 Trench Section at Galvanic Magnesium Anode and Test Station

- Bonded Joints and Test Stations: The pipelines will be installed with test stations as shown in **Figure 4-9** and bonded DIP joints as shown in **Figure 4-10**. The test stations will be provided along the pipelines, at the ends of steel casings, and at utility crossings and will be used during the life of the pipelines to monitor for corrosion. If any readings demonstrate corrosive signatures, the pipelines would be uncovered and inspected, and efforts implemented to mitigate corrosion. Bonded joints and test stations are not required per AWWA Standards and are a means of designing additional protection to the pipelines for the 100-year service life. Pipeline electrical isolation pieces shown in **Figure 4-10** were provided at contract package breaks and ends of the pipelines in order to protect against corrosion induced from connections to adjacent existing or new infrastructure.

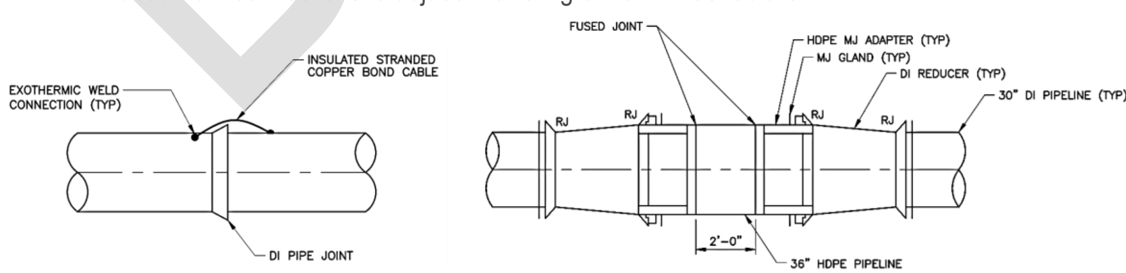


Figure 4-10 Bonded Joints and Electrical Isolation Detail

4.7 Contract Package Breaks

Sequencing constraints have been shown and specified in order to define which contractor will provide pipeline closure at contract breaks for bid-ability purposes and in preparation for disinfection and commissioning. The constraints were developed considering construction schedule. Since the facilities are anticipated to reach substantial completion after the pipelines, the facility contractors were selected as the contractors responsible for providing closure between contracts. The sequencing is summarized as follows:

1. Contract Package 2 will commence pipe laying at contract breaks with the Oklahoma Pumping Station and Contract Package 3 and provide the restrained ductile iron (DI) cap as shown in **Figure 4-11** no later than 90 days after the Notice to Proceed.
2. Contract Package 2 will complete pipe laying, provide pipeline cap marker, backfill, pressure and leakage test as specified in Section 01 45 50, and restore the disturbed area to a point 100 linear feet beyond the contract interface no later than 150 days after the Notice to Proceed.
3. The Oklahoma Pumping Station and Contract Package 3 will provide pipeline closure with Contract Package 2 as shown in **Figure 4-11**.
4. The Oklahoma Pumping Station and Contract Packages 2 and 3 will disinfect and commission the water supply system as described in **Section 6**.

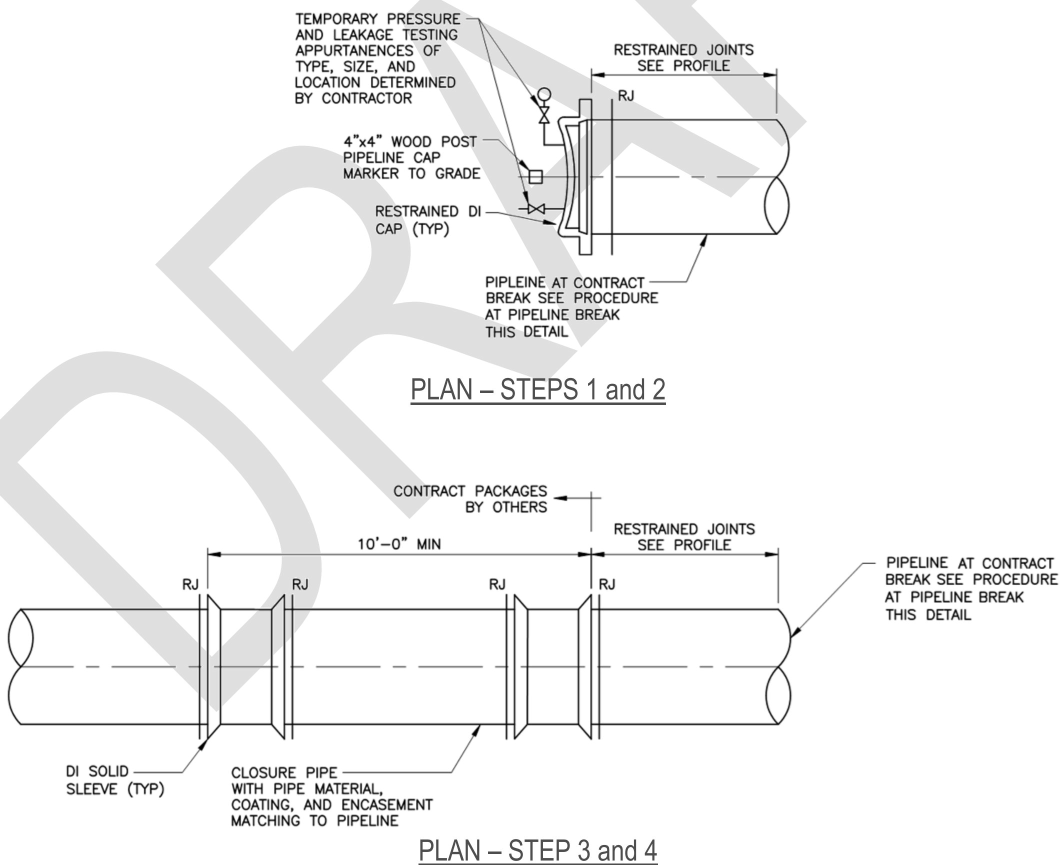


Figure 4-11 Contract Break Detail

SECTION 5 Design Philosphy, Facilities

Facilities supporting Waukesha's new water supply system will be comprised of the BPS, water reservoirs, chemical feed facilities, and WSCB. The following subsections describes the overall design philosophy of the facilities. Note the OPS will be constructed, owned and operated by MWW. An engineering report for the OPS will be submitted separately by MWW as necessary for WDNR approval.

The purpose of the storage, BPS and chemical facilities is to store, and pump potable water received from MWW via the Water Supply Pipeline and convey the water to the WWU Distribution System through the BPS Discharge Pipeline. The water reservoirs provide for emergency storage and provide a hydraulic break between the MWW and WWU Distribution Systems. The BPS has been designed to meet the full range of anticipated demands from WWU. The BPS requires a building to house the pumps, piping, valves, meters, and associated appurtenances to pump the water from the water reservoirs to the WSCB. Chemical addition is provided to supplement the chloramine residual to desired concentrations for the finished water. This subsection describes the design of the water reservoirs, pumping system, chemical feed system, and WSCB.

5.1 Water Storage Reservoirs

The water storage reservoirs are required to provide for emergency storage, attenuate between the different pumping rates of the OPS and the BPS, and provide operational volume for the OPS to conduct filling operations. The water storage reservoirs will be located at the BPS site.

5.1.1 Water Storage Capacity

The effective storage capacity of the water reservoirs was evaluated based on the operational, equalization, and emergency storage as follows:

- **Operational storage** is the volume that supports operation of the OPS pumps between the water levels that the OPS pumps operate between. Storage is calculated based on the 25% of the ADD.
- **Equalization storage** is the volume required to balance the difference in flow from the OPS pumping rate with the diurnal demand of the WWU distribution system. The storage is calculated based on the ADD and MWW's preference to supply water at a steady rate over a 24-hour period.
- **Emergency storage** provides water for events such as Water Supply Pipeline breakage, loss of service from the OPS, power outages, and equipment failures upstream of the water reservoirs. Wisconsin Administrative Code NR 811.62 requires a minimum water reservoir storage of one ADD under normal operating conditions. The emergency storage is calculated based on the two days of storage at ADD of 6.6 MGD which was determined by WWU to be sufficient time to begin emergency pumping from their backup well system. Fire protection for Waukesha was evaluated but not included in the water reservoir volume allocation as the existing storage in the WWU Distribution System was determined to be sufficient.

5.1.2 Water Reservoir Type and Design

After determining the required capacity for the water reservoirs, an evaluation was performed to select an appropriate water reservoir type based on the quantity, configuration, shape, and material.

- **Number of Water Reservoirs:** In order to provide a level of redundancy and allowance for tank cleaning and maintenance, two tanks were selected.
- **Configuration**: Three storage configurations were evaluated for the water reservoirs, including underground, at grade, and elevated. At grade water reservoirs were selected based on the evaluation of the regulations, site constraints, hydraulics, and cost.
- **Shape:** Circular water reservoirs were identified as the preferred shape to provide consistent flow and mixing throughout the water reservoir and reliable structural integrity through uniform stress distribution.
- **Material:** Four material types: bolted steel, welded steel, cast-in-place, and precast pre-stressed concrete were evaluated based on design complexity, rate of installation, capacity, maintenance, life expectancy, durability, aesthetics, and cost. Concrete water reservoirs exhibit more benefits to the operation and maintenance requirements. Precast pre-stressed concrete has the advantage of expedited installation process and uniform quality inspection over cast-in-place concrete and, therefore, was selected as the water reservoir material.
- **Dimensions**: After evaluating the several combinations of water reservoir diameter to side water depth (SWD) based on feasibility, cost, applicable regulations, site and system design parameters, and hydraulics, two 210-foot diameter water reservoirs with SWD of 33 feet were selected.

The dimensions and SWD associated with the different storages are summarized in **Table 5-1**.

Table 5-1 Water Reservoir Storage Volumes and Side Water Depths

	Existing Conditions		Approved Diversion	
Description	Volume (MG)	Height (ft)	Volume (MG)	Height (ft)
Total Effective Storage	16.0	31.0	16.0	31.0
Operational Storage	1.6	3.2	2.0	3.9
Equalization Storage	1.2	2.3	1.5	2.9
Emergency Storage	13.2	25.5	12.5(1)	24.2
Dead Storage (Top of Concrete to Low Water Level)	1.0	2.0	1.0	2.0
Total	17.0	33.0	17.0	33.0

Note:
1. Two days at 8.2 MGD ADD will require the 12.5 MG from the water reservoir and 3.9 MG of storage contribution from the WWU Distribution System Central Pressure Zone.

Inlet and Outlet Piping: Each water reservoir will be served by a separate inlet and outlet pipe that will enter through the floor and feed to and draw from the reservoir at the opposite sides of the water reservoir to prevent short circuiting. The inlet pipe will rise above the high water level and will turn slightly and end at a bend with an invert 6-inches above the high water level, thereby providing an air break between the Water Supply Pipeline and the water reservoirs. The outlet will be 6-inches above the floor of the water reservoir with an anti-vortex plate to decrease water turbulence and prevent vortexing.

Mixing System: For a large diameter water reservoir that is normally operated in a simultaneous fill and draw mode, the inflow velocities typically do not provide adequate mixing energy to avoid dead zones and vertical stratification. In a constant pressure pumping system with variable speed pumps, water reservoir levels do not normally fluctuate significantly during the day and may not provide require turnover to maintain the water quality. A good mixing system in the water reservoir avoids dead zones, short circuiting, vertical stratification, and eliminates need for turnover to maintain water quality. The mixing system can also assist in mixing chemicals introduced into the reservoirs.

Two methods of water reservoir mixing evaluated were hydrodynamic mixing and mechanical mixing as described in the following subsections.

Hydrodynamic mixing utilizes the impact of water flowing through specialized nozzles along a pipe header with stationary water in the water reservoir. This method takes advantage of the incoming jet's momentum and the natural mechanism to transfer it to surrounding water masses. The system is designed such that a complete mix of the water reservoir can be achieved within a set amount of time. The hydrodynamic mixing system would be installed during water reservoir construction.

The initial capital cost of hydrodynamic mixing systems is higher than other options, but the system provides greater flexibility for operation and maintenance. In particular, routine maintenance is required only for the recirculation pumps at the BPS, whereas the mixing system components within the water reservoir do not come with routine maintenance requirements. The life expectancy of the nozzles is 30 years or greater.

Due to the need for an air break between the water supply from MWW and the water reservoirs, a recirculation line from the pump suction line at the BPS would be installed to supply flow and pressure for the mixing system. Two recirculation pumps located at the BPS would supply sufficient mixing pressure. A third, swing pump would be installed to maintain water quality, if a pump is down for maintenance.

Mechanical mixing blends water through electric submersible mixers. The quantity, size, and power of mixers are determined based on the water reservoir volume and flow in and out of the water reservoir. Mechanical mixers do not rely on the water entering the water reservoir for mixing. Installation of the mixers could be done through the roof access hatch by lowering the devices with chains. The chains would also be used to support maintenance operations by lifting the mixer and then lowering it to the ground outside the water reservoir. Electrical wiring from a power source would feed from the top of the water reservoir to supply power to the mixers. The mixers typically use motors less than 5 horsepower. The capital cost of mechanical mixers is less than that of hydrodynamic mixing systems but the operation and maintenance costs are greater. The life expectancy of mechanical mixers is five to seven years. Multiple mixers may be required for the large diameter water reservoirs.

The hydrodynamic mixing system provides the benefits of little to no maintenance within the water reservoir and high life expectancy. For these reasons, the hydrodynamic mixing system was selected.

Water Reservoir Appurtenances: The water reservoirs will also include the following appurtenant design aspects:

- Frost-resistant, vacuum relief security shroud roof vent with a stainless steel 24-mesh corrosion resistant screen.
- Aluminum exterior ladder and fiberglass interior ladder, both conforming to applicable OSHA standards.
- A weather proof aluminum roof hatch with lockable, hinged cover, gasket and curb frame.
- Overflow piping and weir system.

5.2 Booster Pumping Station

The BPS will be the sole source of water and responsible for pumping to the City of Waukesha on a continuous basis. The BPS will also need to meet the diurnal demand of the City of Waukesha. The BPS will be designed to meet the existing conditions and have the flexibility to increase capacity as needed to meet future demands associated with the maximum withdrawal approved by the Compact Council. The demand conditions are summarized in **Section 3**.

5.2.1 Site Selection

WWU does not own a site that can support the BPS and associated reservoirs. A site selection evaluation was performed in conjunction with the Milwaukee Route Study to determine a location for the BPS.

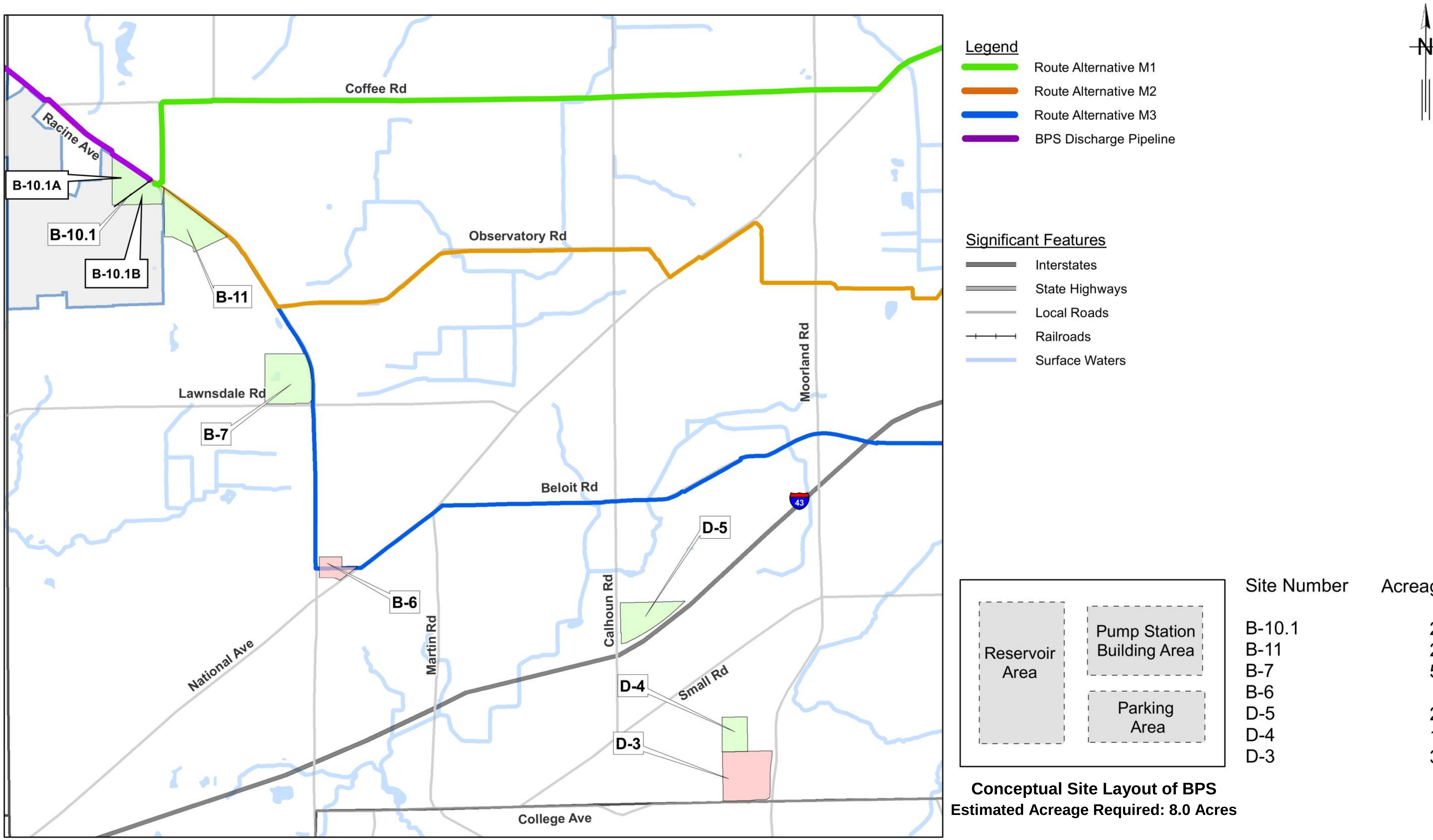
Screening for a potential BPS site consisted of field reconnaissance, desktop analysis, evaluation, and comparison of the possible sites. Pipeline and site hydraulics and surface features were identified for each site. Field reconnaissance was completed to perform a visual review with regard to existing site conditions, open space, and adjacent lands. Upon completion of the field reconnaissance, the list of potential sites was refined, and a desktop analysis was conducted on the remaining sites to provide information to be used for comparing and ranking. The desktop analyses evaluated the following subject areas:

- Hazardous materials
- Archaeological
- Wetlands and waterways
- Floodplain and floodway
- Site size and elevations

Figure 5-1 shows the sites that were considered. Since site selection occurred concurrently with the route studies, sites were not selected if they were not along the water supply route. Each of the sites was rated based on the subject areas. Sites B-6 and D-3 were eliminated from further evaluation due to cultural and environmental concerns. Site screening of Site B-6 revealed potential on-site and off-site sources of contaminated soil, groundwater or vapor migration. Site D-3 was found to contain wetlands throughout the site. Since the BPS is an unmanned facility, the sites closer to Waukesha were preferred due to ease of access and maintenance. The area around Site B-10 was preferred over Sites B-7, B-10.1, D-4, and D-5 as it is closer to the Waukesha, which will require a shorter pipeline from the facility to Waukesha. The area around Site B-10 is also located at higher elevations than other sites, which would minimize the need for repumping downstream of the BPS.

Upon further evaluation of the area around Site B-10, multiple adjacent locations were considered. The new locations were assigned designations as Site B-10.1 (southwest corner of South Swartz Road and South Racine Avenue) and Site B-10.2 (southeast corner of South Swartz Road and South Racine Avenue) of which Site B-10.1 was preferred due to its ownership by the Waukesha County Department of Parks and Land Use (DPLU). Site B-10.1 is situated in Minooka Park and land transfer can be effectively coordinated between the DPLU and WWU.

Site B-10.1 contains a wetland that separates the Site B-10.1 into two potential areas for the BPS. Both areas of Site B-10.1 were considered. The area located to the west of the wetland was designated as Site B-10.1A and the area to the east of the wetland was designated as Site B-10.1B.



Site Number	Acreage
B-10.1	27
B-11	29
B-7	57
B-6	9
D-5	25
D-4	13
D-3	36

Figure 5-1 BPS Site Selection Map

Conceptual site plans were prepared for Sites B-10.1A and B-10.1B and reviewed with WWU. Due to a number of site constraints present with Site B-10.1A, such as wetland limits and environmental corridor location, Site B-10.1B was selected as the preferred site. The advantages of Site B-10.1B include flexibility for site components, building layouts, site access, and hydraulics. The reservoirs can be located away from South Racine Avenue, a major arterial, to reduce the visual impact of the reservoirs. The building can be located toward South Racine Avenue and incorporate architectural aspects that are visually appealing.

5.2.2 Pump Design and Selection

Pump Type: Two types of pumps were evaluated: axial split-case dry-pit style with the shaft centerline oriented horizontally, commonly known as horizontal split-case (HSC) dry-pit style and lineshaft-driven vertical turbine (VT) pumps. Each pump type has been evaluated in terms of site requirements, priming requirements, net positive suction head (NPSH), hydraulic efficiencies, ease of maintenance, and spatial requirements.

The hydraulic efficiencies of these two pump types are similar. The pump and motor base can be smaller for VT pumps than HSC pumps, reducing the area required for the base as well as the spacing between the pump discharge piping, which would support a smaller footprint for the BPS. VT pumps provided more flexibility for site grading and water reservoir design due to the NPSH requirements. The VT pumps offer cost savings in the pump equipment, building, water reservoir, and site work. Due to these benefits, the VT pumps were selected.

Pump Size and Number: In order to select the size and number of pumps, many factors were evaluated, including range of flow, level of redundancy, operational flexibility and future conditions. The flow data provided by WWU from 2012 to 2016 was used to select the number and size of the pumps. In order to determine the number and size of pumps, hourly data was needed since the BPS will need to supply flow based on the diurnal curve of the demand on any given day. The hourly flow data for the existing conditions was determined applying the diurnal curve to each day of the data set provided by WWU from 2012 to 2016. The data was then sorted in ascending order to produce the cumulative percentile curve shown in **Figure 5-2**.

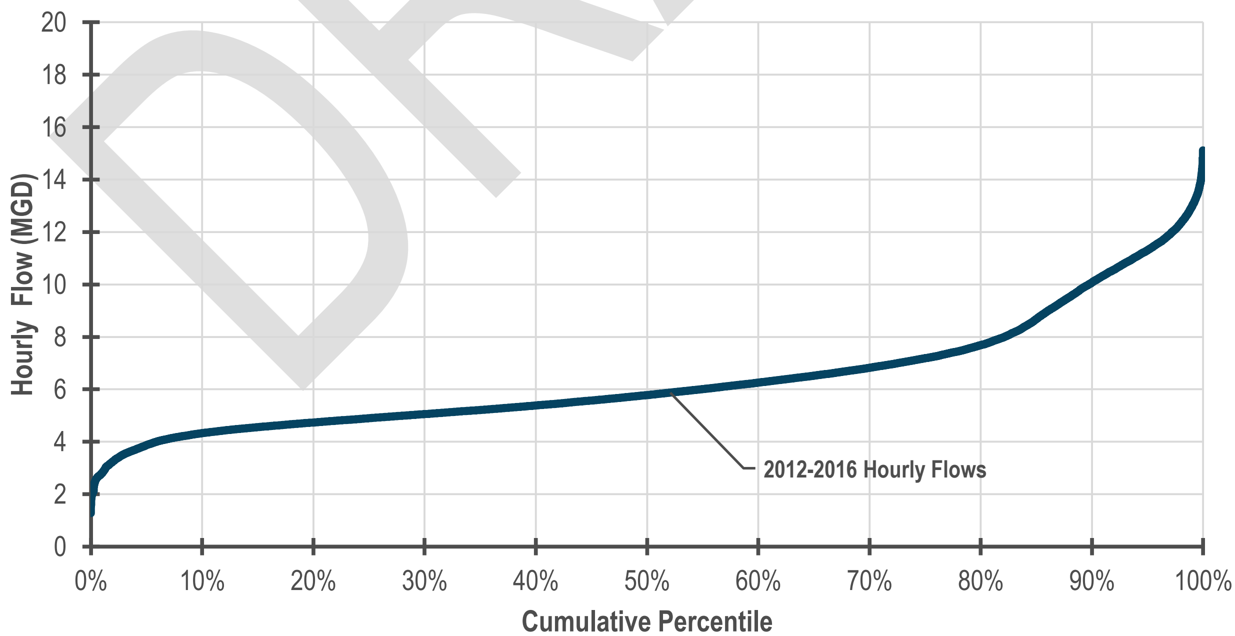


Figure 5-2 Flow Cumulative Percentile Curve

Figure 5-2 shows that for the existing conditions data set, 80% of the hourly flow (between 10% and 90%) is within a range of 4.25–10.10 MGD. One pump sized at 6 MGD can provide flow for half of the data set. In order to limit the number of pumps installed, pump sizes between 5 and 6 MGD were evaluated.

To determine the number of pumps, the level of redundancy was evaluated. Pumping stations are typically designed to supply the firm capacity with one of the largest pumping units out of service. This is often referred to as an N+1 configuration, with "N" being the number of pumps to provide the firm capacity. To evaluate the number of pumps required, the PHD value from the data set of 15.75 MGD was divided by the top and bottom range of the targeted pump sizes (5 and 6 MGD). This yields values of 2.6 and 3.1, or approximately an integer value of 3, which is the number of pumps to provide the firm capacity for the BPS. To provide a firm capacity of 15.75 MGD, each pump is rated for 5.25 MGD. Taking the value of 3 as "N", the total number of pumps was determined to be 4. The total BPS capacity with all 4 pumps in operation is 21.0 MGD.

The pump selection provides operational flexibility over a wide range of flow for the existing demand conditions. Typical turn down on a pump is approximately 50%, which yields a pumped low flow of 2.63 MGD. Based on the hourly flow data, the probability of the flow being below this value is 0.5%. Flows below the capacity of a pump can be accommodated with recirculation lines or jockey pumps, if necessary. Recirculation lines were selected to eliminate the need for additional pumps. Further, two pumps at rated capacity will satisfy the flow demand over 90% of the operating time. **Table 5-2** summarizes the pumping capacities compared to the probability of occurrence in the data set and the linear percent of the design peak hour demand (PHD).

Table 5-2 Existing Conditions Pumping Capacity

No. Pumps Operating	Existing Conditions Capacity (MGD)	Percent of Time Flow in Data Set is Below Pumping Capacity (%)	Percent of Design Peak Hour Demand (15.1 MGD) (%)
One Pump (Low Flow)	2.63	0.5%	17%
One Pump	5.25	36%	35%
Two Pumps	10.50	91%	70%
Three Pumps (N or Firm Capacity)	15.75	100%	104%
Four Pumps (N+1 or Installed Capacity)	21.00	NA	140%

In the future, it may be necessary to increase the BPS capacity to accommodate increased demand or growth. The PHD associated with the Approved Diversion of 8.2 MGD ADD is 19.0 MGD. This would require an additional 3.25 MGD of installed capacity. Two options to increase capacity would be to replace two of the pumps with higher capacity pumps or all four pumps. **Table 5-3** shows the pump selection for existing conditions and options for the future. Future Option 2 allows greater flexibility for phasing the pumps over time and allows for use of the existing pump barrels and discharge piping.

Table 5-3 Options for Increasing Pumping Capacity

Pump No.	Existing Conditions	Future Option 1 – Replace 2 Pumps	Future Option 2 – Replace All Pumps
BP - 1 (MGD)	5.25	8.50	6.33
BP – 2 (MGD)	5.25	5.25	6.33

Pump No.	Existing Conditions	Future Option 1 – Replace 2 Pumps	Future Option 2 – Replace All Pumps
BP – 3 (MGD)	5.25	5.25	6.33
BP – 4 (MGD)	5.25	8.50	6.33
Firm Capacity (MGD)	**15.75**	**19.00**	**19.00**
Installed Capacity (MGD)	**21.00**	**27.50**	**25.33**

Pumping Hydraulics: Pumping hydraulics were analyzed to maintain pressure set point HGL of 1,120 feet at the BPS pressure transmitter described in the BPS operations. The BPS operation and pressure set point HGL are presented in **Section 5.2.3**. The discharge head of the Booster Pumps is determined based on the sum of the static and dynamic heads. The static head is the water level elevation difference between BPS pressure set point HGL and the water reservoirs. The dynamic head is the head required to overcome the resistance to flow in the pipeline and includes losses due to pipe friction and turbulence in various fittings. The minimum and maximum pump discharge head are presented in **Table 5-4**. The maximum discharge head of 145 feet will be the pump design discharge head. The system curves and pump curve (for one of the selected pump manufacturers) are shown in **Figure 5-3**. Pump curves are shown for one, two, and three pumps operating at full speed in parallel.

Table 5-4 BPS Discharge Head

Parameter	Minimum Discharge Head	Maximum Discharge Head
Water Reservoir Water Level, feet	1,013 (High Water Level)	982 (Low Water Level)
BPS Pressure Set Point HGL, feet	1,120	1,120
Hazen-Williams C	150 (New Pipe)	120 (Aged Pipe)
Total Static Head, feet	107	138
Dynamic Head, feet	1.0 (@ 3.0 MGD)	7.0 (@ 15.75 MGD)
Total Head, feet	108	145

Low Flow Condition and Recirculation: The existing minimum hour demand of the BPS is 1.2 MGD, which occurs rarely based on 2012-2016 data provided by WWU and is lower than the minimum flow recommended by the pump manufactureres for pumps with these head requirements. The minimum recommended flow for pumps from different manufacturers varied from 1.75 MGD to 3.23 MGD. To satisfy the low flow conditions, either the flow above 1.2 MGD could be recirculated to meet the minimum stable flow condition of the pump or a jockey pump of smaller capacity could be used. Adding a jockey pumping system will add the capital cost of the pumping system as well as increased size of the building. This additional cost compared to the addition of recirculation line is not justifiable for the rare low flow conditions when jockey pumps would be used. Therefore, a recirculation line was provided to meet the low flow conditions. A BPS Discharge Pipeline flow set point will be programmed into the control logic such that when the flow leaving the BPS is below the minimum flow set point for the Booster Pump, the recirculation line will open and recirculate a set flow rate in order to allow a single pump to operate within an acceptable flow range of the pump. A pressure reducing valve on the recirculation line will reduce the higher pressure on the discharge header side to the lower pressure on the suction header.

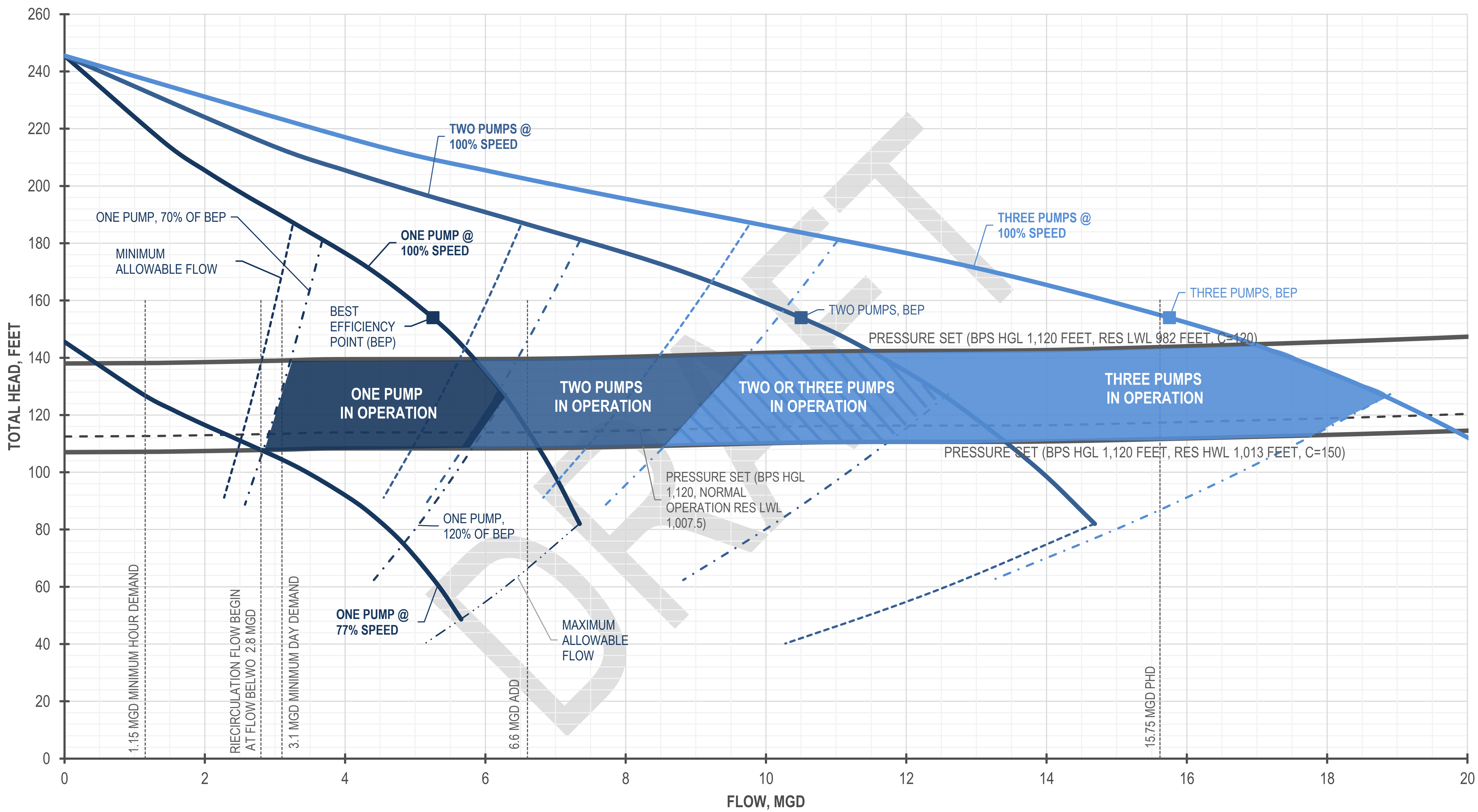


Figure 5-3 System Curves and Pump Curves

5.2.3 BPS Sequence of Operation

BPS Operation: The operation of the number of Booster Pumps and modulation of individual pump speed is determined by the BPS Discharge Pipeline pressure set point. The target HGL for the BPS Discharge Pipeline is 1,120 feet at the pressure transmitter located in the BPS basement. The target HGL was determined to maintain a minimum of 35 psi at the high point of the BPS Discharge Pipeline at elevation 992 feet located approximately 800 feet downstream of BPS at all flow conditions and maintain a pressure required for operation of WSCB during all operating conditions.

As the BPS will be operating based on the BPS Discharge Pipeline pressure set point, any disruption in the BPS communication with WSCB and OPS will not affect the operation of the Booster Pumps.

When the water level in the water reservoir will reach its Low Water Level, the Booster Pumps will shut down to prevent damage to the pumps.

Booster Pumps Operation: Each pump will have a variable frequency drive (VFD) to adjust pump speed based on a pre-determined pressure set point. The Booster Pumps will be configured with one pump designated as Lead Pump and operating during normal conditions, and the subsequent pumps designated as Lag 1 Pump, Lag 2 Pump, and Standby Pump. The operator will have ability to change the pump designation through supervisory control and data acquisition (SCADA).

During normal operation, the Booster Pumps will be operated to maintain the BPS outlet pressure set point of 1,120 feet HGL to provide that adequate pressure is provided to the WSCB under all operating conditions. The Lead Pump will adjust speed to maintain BPS Outlet Pressure set point until either reaching the allowed maximum pump speed or the pump minimum flow rate set point for a predetermined amount of time.

The Lag 1 Pump will be operated to maintain BPS Outlet Pressure set point and will start when Lead Pump has reached maximum speed for a predetermined amount of time. During auto start, Lag 1 Pump will increase speed until reaching the discharge pressure set point. After Lag 1 Pump control valve opens, Lead and Lag 1 Pumps will adjust speed until both pumps operate at the same speed to maintain the BPS Outlet Pressure set point. The operating pumps will adjust speed to maintain the BPS Outlet Pressure set point until either reaching the maximum allowed speed or a combined minimum flow set point for a predetermined amount of time, at which point both pumps will operate at constant speed. At the minimum flow set point, Lag 1 Pump will stop after either Lead or Lag 1 Pump has been in operation at minimum speed for a predetermined amount of time, or both pumps have been operating at or below the combined minimum flow set point for a predetermined amount of time.

Operation of Lag 2 Pump will have a similar operating philosophy as Lag 1 Pump. The pump designated as Standby Pump will auto start upon failure of any of the operating pumps, and will assume the operation of the failed pump.

For pump start-up, the Booster Pump will be started with its corresponding pump control ball valve in the closed position. When the pressure at the pump discharge piping reaches a predetermined set point, the control valve will be released to fully open at a predetermined speed. Prior to pump stop, the associated control valve will initiate closing sequence at a predetermined speed to prevent pump reverse rotation and to reduce water hammer. In addition, a pump tripped status or a power failure will automatically close a control valve.

The BPS shutdown will be initiated when the water reservoir water level is at low water level. Individual pump shutdown will also be initiated if the pump discharge pressure is greater than the predetermined set point for the predetermined time or pump temperature or vibration trip signal is active.

5.2.4 Water Supply Pipeline Pressure Sustaining Valve

The 30-inch Water Supply Pipeline will branch in to two 24-inch Reservoir Supply Pipelines in the basement of the BPS. Both 24-inch Reservoir Supply Pipelines will reduce down to a 16-inch pressure sustaining ball valves that will maintain minimum 35 psi pressure in the Water Supply Pipeline.

5.2.5 Water Supply Yard Piping HGLs

The 30-inch BPS Supply conveying water from the water reservoirs to the BPS suction header will be the only gravity pipe at the BPS site. All other water supply yard piping will be under pumped pressure by different pumping systems and will always have HGLs above the established grade elevation. The static head exerted by the water level in the reservoirs will keep the HGL in the Reservoir Supply Pipeline above the proposed grade.

5.2.6 Security Provisions

Each facility will include security measures, including access control. Video monitoring systems will be included for some facilities. Building security will be provided through use of lockable doors and key card access. Intrusion detection equipment, including door switches and digital video cameras will be furnished and installed to allow real time monitoring and alarming at remote locations. Entry to the BPS site will be controlled by a perimeter fence and an access slide gate with electronic access. All networking equipment will be located in either key lockable rooms or locked enclosures for added protection.

5.2.7 Standby Power

In the event of a failure or power outage from the utility, standby power will be provided by an on-site natural gas-fueled generator. The generator system is sized to support pumping operation for ADD flow as required under the Wisconsin Administrative Code. The generator will be furnished in a weather-protected, sound-attenuated enclosure. The generator will be located outdoors, adjacent to other outdoor electrical equipment.

5.3 Chemical Feed Facilities

Chemical Feed Dosage Methodology: To determine the appropriate dosage of chemical to be applied at the BPS, a one-year pipe loop study was completed. The study measured the dosage of chemicals present at various flow rates and throughout different seasons. Pipe loop test results will be submitted as a separate report. The findings of the pipe loop test were used to size the necessary equipment located at the BPS.

Chemical Application: Disinfection of WWU's drinking water will be provided by chloramines, a combination of chlorine and ammonia molecules, once the GWA project is complete and receiving water from MWW. The BPS will serve to boost both water pressure and the residual disinfectant chemical present at the site. Two chemicals will be used at BPS by WWU to create chloramine, sodium hypochlorite and liquid ammonium sulfate (LAS). Dosages for each chemicals where developed based on the chemical concentrations for chlorine and ammonia needed to meet the WDNR residual concentration requirements for the full range of anticipated operating conditions during winter and summer months.

Sodium hypochlorite and chlorine gas were considered for disinfection as they are both effective disinfectants. Over recent years, sodium hypochlorite has become more popular as a disinfectant as there is lower potential for health risks and injuries to operators compared to chlorine gas. In addition, WWU currently uses sodium hypochlorite as their disinfectant at their facilities. Therefore, 12.5% sodium hypochlorite was recommended and used during detailed design.

WWU stated a preference for a liquid form of ammonia, LAS (38-40%) and aqueous ammonia (19% or 33%) were available from the local chemical supplier and evaluated. LAS is the more common option and available in a higher concentration; 40% LAS was recommended and used during detailed design.

In order to create chloramine, liquid solutions containing chlorine and ammonia are dosed to the water source. The typical relationship between the two chemical molecules varies from 3:1 to 5:1, chlorine to ammonia. The dosages recommended by the loop test are 4:1.

There are two application points for the chemical feed system. The first is the water reservoir mixing lines of each water reservoir located in the BPS and the second is the BPS discharge header. The injection locations will be under continuous pressure of approximately 40 feet at the water reservoirs and approximately 145 feet at the BPS discharge header and will include antisiphon / backflow prevention valves. Dosages as determined from the pipe loop test and associated flow rates at each application point are located in **Table 5-5**.

Table 5-5 Chemical Dosage Rates

Design Parameter	Minimum Hour Demand	Initial Average Day Demand	Approved Average Day Demand	Approved Maximum Day Demand	Approved Peak Hour Demand
BPS Flow (MGD)	1.2	6.6	8.2	13.6	19.0
Sodium Hypochlorite:					
Target Cl2 Boost Concentration (mg/L)	0.30	1.25	1.25	1.25 - 4.00	4.00
Feed Rate:					
Each Reservoir Mixing (gph)	--	1.52	1.89	3.15 - 10.07	--
BPS Discharge (gph)	0.13	3.05	3.79	6.30 - 20.14	28.13
Liquid Ammonium Sulfate:					
Target NH3-N Boost Concentration (mg/L)	0.08	0.31	0.31	0.31 - 1.00	1.00
Feed Rate:					
Each Reservoir Mixing (gph)	--	0.39	0.48	0.80 - 2.56	--
BPS Discharge (gph)	0.03	0.78	0.97	1.60 - 5.13	7.17

Note: Target Cl2 concentration of 0.30 mg/l is the minimum anticipated, with 1.25 mg/l being under normal operating conditions and 4.0 mg/l being worst case scenario.

Addition of a corrosion inhibitor and fluoride at BPS was considered but determined to not be required at this time. However, a third chemical room is provided in the building for future use. Further evaluation of corrosion inhibitor application is on-going under a separate project and the project team will continue to work with WDNR separately on this item.

Chemical Rooms: Three chemical rooms are located in the BPS on the first floor. Two rooms will be used for sodium hypochlorite and LAS, respectively. The remaining room will be reserved for a future chemical if needed. Each room has a set of double doors with outdoor access where chemical trucks will be able to unload bulk chemical. The bulk storage, day tanks, transfer pumps, and chemical feed pumps will be located on a recessed floor in a containment area. A platform will be located in the northeast corner of the room with the chemical supply connections and exterior access doors. Chemicals will be transferred through chlorinated polyvinyl chloride (PVC) pipes from the chemical rooms to the three application points located in the basement of BPS. Separate vents from the bulk storage tanks will be piped directly to exterior of the building. Safety showers and eyewash stations will be provided where necessary in accordance with Occupational Safety and Health Administration (OSHA) and American National Standards Institute/International Safety Equipment Association (ANSI/ISEA).

Chemical Equipment: For each chemical, two bulk storage tanks will be sized to house the combined chemical volume required for 30-day average demands. The bulk storage tanks will feed into a smaller day tank sized to hold 3-days worth of chemical at average day demand. The day tank will be fed from the bulk storage tanks by one of the two transfer pumps. The transfer pumps require a flooded suction to operate and are located along the western wall of the chemical room. Each storage tank will include a radar level controller. Bulk storage tanks will be filled regularly. **Table 5-6** describes the parameters for the storage tank and transfer pumps.

Table 5-6 Storage Tank and Transfer Pumps

Description	Sodium Hypochlorite	Liquid Ammonium Sulfate (LAS)
Bulk Storage Volume (gal)	1,900 (Quantity 2)	550 (Quantity 2)
Day Tank Storage Volume (gal)	400 (Quantity 1)	120 (Quantity 1)
Storage Tank Material	Polyethylene	Polyethylene
Transfer Pump	Centrifugal Seal-Less Magnetic Drive	Centrifugal Seal-Less Magnetic Drive
Transfer Pump Design Point	20 gpm	20 gpm
Discharge Pipe Diameter (in)	1.5”	1.5”
Time to fill Day Tank (min)	20	6

Chemical feed pumps will draw chemical through the top of the day tank. Six chemical feed pumps for each chemical are provided, one lead and one lag pump will feed the each of the reservoir mixing lines and the BPS discharge header under normal operating conditions. All chemical feed pumps will be selected to meet the higher pressure required for the BPS discharge header application point. Valves will be provided in the feed pump discharge piping to provide flexibility of assigning chemical feed pumps to individual application points to meet the worst case scenario/emergency condition feed rates (at a Cl2 boost of 4 mg/l).

Chemical feed pumps will be controlled by analyzers located at either the Water Supply Pipeline, BP Supply Line or at the WSCB that sample for chloramine constituents, chlorine and ammonia, to determine their respective concentrations. Chemical feed pumps will be controlled by BPS PLC which uses the information received from the analyzers and a target total chlorine and free ammonia concentrations to determine the required dosage of each chemical and the pump speed for each location. Interlock signals will be provided from the BPS PLC to the reservoir mixing pumps. Interlock signals will prevent the chemical feed pumps from operating when the reservoir mixing pumps are not operating. **Table 5-7** describes the parameters for the chemical feed pumps.

Table 5-7 Chemical Feed Pumps

Description	Sodium Hypochlorite	Liquid Ammonium Sulfate (LAS)
Maximum Required Feed Rate (Normal Operating Conditions)	6.30	1.60
Maximum Required Feed Rate (Emergency Operating Conditions)	28.13	7.17
Chemical Feed Pump Type	Peristaltic Pump	Peristaltic Pump
Chemical Feed Pump Capacity	0.01/7.13 gph @ 100 psi	0.01/7.13 gph @ 100 psi
Number of Pumps	6	6
Total Nominal Firm Capacity (5 Pumps @ 50% Speed)	17.83	17.83
Total Maximum Firm Capacity (5 Pumps @ 100% Speed)	35.65	35.65

5.4 Water Supply Control Building (WSCB)

The WSCB is required to house valves necessary to maintain pressure above 35 psi along the BPS Discharge Pipeline and reduce pressure to within the current operating HGL of the WWU Distribution System's Central Pressure Zone.

5.4.1 Site Selection

Downstream of the water reservoirs and BPS, the BPS Discharge Pipeline will connect to the WSCB, which will connect to WWU's Distribution System along Les Paul Parkway at a 24-inch trunk main. Distribution system modeling was performed as part of the Program to evaluate the preferred connection point to WWU's Distribution System. The evaluation included four alternative connection points, shown in **Figure 5-4.**

The alternatives were evaluated based on distribution system improvements required to accommodate each connection point, available land to locate the WSCB, and cost. It was determined through hydraulic modeling efforts that each connection alternative would require similar distribution system improvements to accommodate the water supply transition. AACE Class 5 OPCCs are presented in **Table 5-8** relative to the least costly alternative**.**

Table 5-8 Connection Specific Costs

Connection Alternative	AACE Class 5 Comparative Opinion of Probable Construction Cost (OPCC)
1	-
2	$4.6M
3	$1.7M
4	$11.9M

The potential connection points were discussed with WWU and it was determined that the connection point at Les Paul Parkway and Sunset Drive (Connection Alternative 1) is preferred due to its proximity to Parcel WAKC 1349999 owned by WWU that will be used to locate the new WSCB, cost, and ability to satisfy hydraulic requirements.

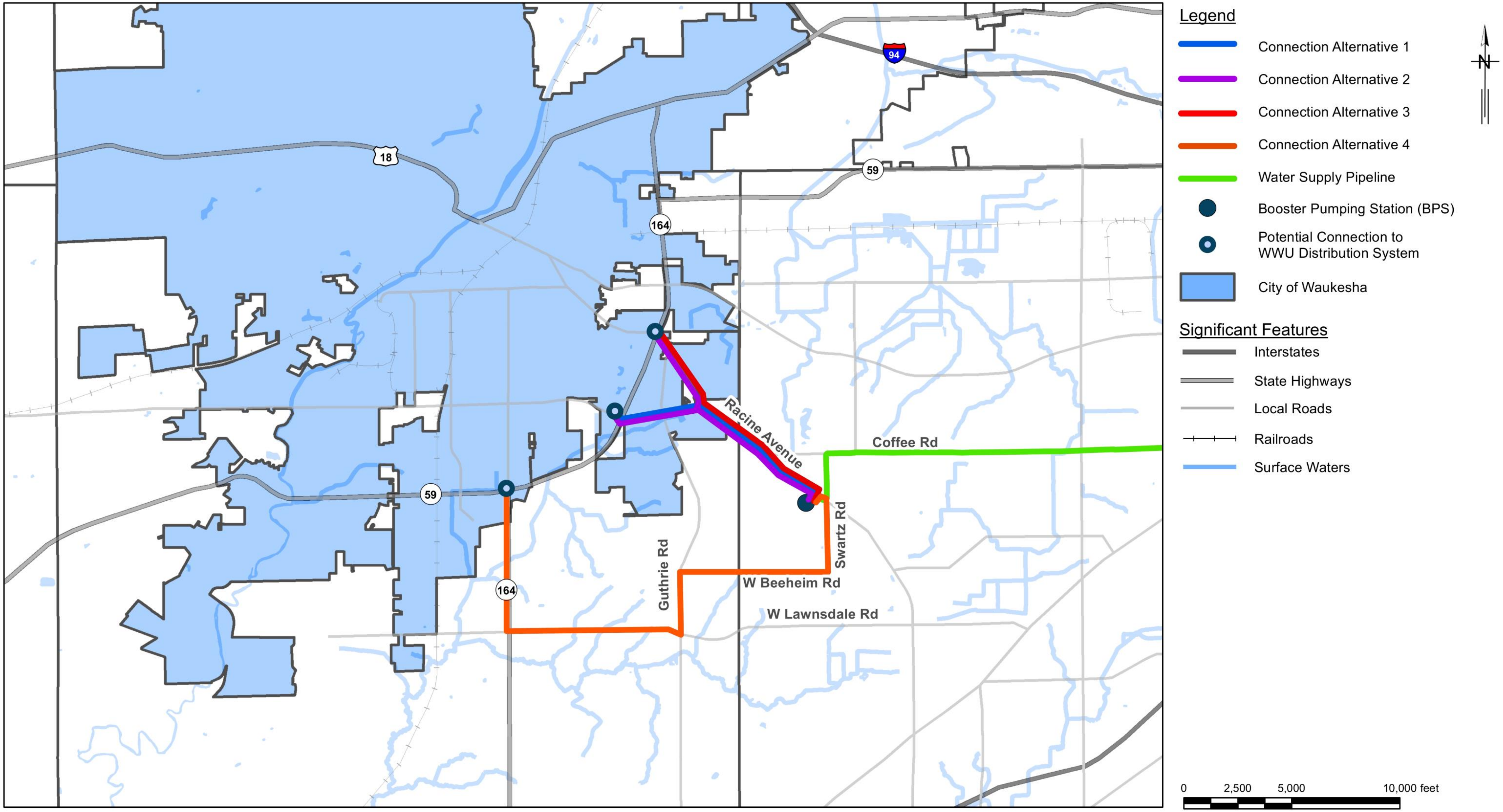


Figure 5-4 Water Supply Connection Alternatives

5.4.2 Design and Operations

The WSCB will house one 10-inch and two 14-inch PSRVs on the connection of BPS Discharge Pipeline to the discharge connection to the Central Pressure Zone. The pressure reducing set point of the PSRVs will be adjustable, approximately 60 psi, with three different initial set points of 57, 59, and 61 psi for the three PSRVs.

The pressure sustaining set point for all PSRVs will be 104 psi to close valves on an upstream (BPS Discharge Pipeline) HGL at or below 1,100 feet. Based on the flow and pressure settings, PSRV No.1 will be set to pass up to 5 MGD and maintain a downstream HGL of 1,000 feet. Once the demand increases, the flow through PSRV-1 will be capped at 5 MGD, therefore, pressure will drop on the downstream of valve. The pressure will continue to drop to the PSRV-2 set point at which point, PSRV-2 will open to pass the flow and maintain its discharge pressure set point. On increasing demand, PSRV-1 and PSRV-2 will operate together and provide up to 14 MGD. If the demand increases above 14 MGD, the pressure will continue to drop and PSRV-3 will open to pass flow and maintain its pressure set point. Pressure set points could alternate within PSRVs to allow for wear equalization. If required, the PSRVs could pass flows above the capped flow. The initial pressure set points and respective HGLs for PSRVs are summarized in **Table 5-9**.

Table 5-9 WSCB Pressure Sustaining/Reducing Valves Set Points

Valve	Size inches	Pressure Sustaining psi	Pressure Sustaining HGL, ft	Set Flow MGD	Pressure Reducing psi	Pressure Reducing HGL, ft
PSRV No. 1	10	104	1,100	5	61	1,000
PSRV No. 2	14	104	1,100	9	59	995
PSRV No. 3	14	104	1,100	9	57	990

The WSCB will also house the interconnection between the Southeast Highline BPS and the BPS Discharge Pipeline allowing connection to Hunter Tower. The connection will allow water from the Highline BPS or the Hunter Tower to supply the BPS Discharge Pipeline in the event the BPS is not in operation. The PRV on the interconnection will have a pressure reducing set point of 96 psi (HGL of 1,080 feet) on the BPS Discharge Pipeline. In the event the BPS Discharge Pipeline pressure drops below an HGL of 1,080 feet, the PRV will open to allow flow from the Southeast Highline BPS or the Hunter Tower to maintain required minimum pressure in the BPS Discharge Pipeline and at the BPS.

5.4.3 Security Provisions

The WSCB security system will include site monitoring equipment and building access control. The site will be monitored by closed circuit television, and monitoring equipment will consist of cameras around key points of the building. Physical access to the WSCB will be monitored and controlled via electronic access at the main entrances.

SECTION 6 Leakage Testing, Disinfection, and Commissioning

The leakage testing, disinfection, and commissioning of Waukesha's new water supply system has been developed as a system-wide, coordinated approach in accordance with NR 811.73(2)(c) and NR 811.73(2)(d) based on the following general criteria:

- Leakage testing will be completed in accordance with AWWA C600 Installation of Ductile-Iron Mains and Their Appurtenances at any time prior to disinfection using potable water from any source.
- Disinfection will be completed in accordance with AWWA C651 Disinfecting Water Mains.
- Each contractor will be held responsible for leakage testing and disinfecting equipment, water reservoirs, pipe, fittings, valves, and other appurtenances within their respective contract package.

Figure 6-1 shows methods for the disinfection and commissioning process for the new water supply system with MWW potable water. Other methods could be used during construction. However, key requirements necessary for the disinfection of Waukesha's new water supply system listed in **Table 6-1** have been specified for the contractors to adhere to in order to support the successful completion of the water supply transition and allow methods like those shown in **Figure 6-1** to be implemented.

Table 6-1 Specification Section 33 13 00 Disinfection Requirements

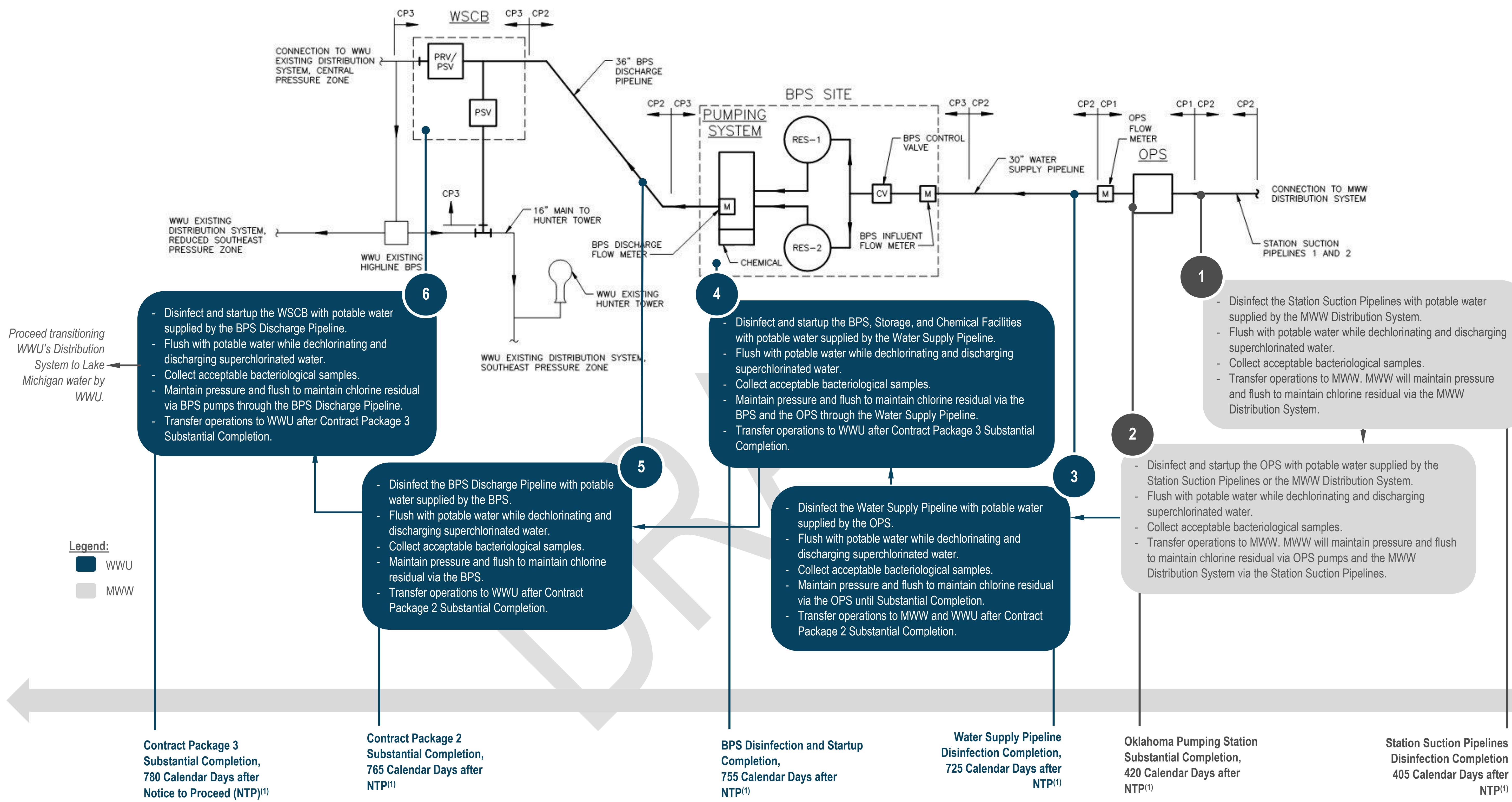
Item	Oklahoma Pumping Station	Contract Package 2	Contract Package 3
Video	Not applicable	- Submit a color audio-visual recording of the entire inside of the pipelines prior to disinfection. Remove materials found in pipelines prior to disinfection.	Not applicable
Source Water	- Disinfect using potable water supplied by MWW.	- Disinfect using potable water supplied by MWW for the Station Suction and Water Supply Pipelines. - Disinfect using potable water supplied by MWW or WWU for the BPS Discharge Pipeline.	- Disinfect using potable water supplied by MWW for the BPS. - Disinfect using potable water supplied by MWW or WWU for the WSCB.
Samples	- Take responsibility for collecting bacteriological samples.		
Pressure	- Maintain a minimum pressure of 35 psi after disinfection and until after substantial completion when operations are turned over to MWW or WWU.		
Chlorine Residual	- Flush with potable water after disinfection as necessary to maintain a minimum total combined chlorine concentration of at least 1.0 mg/L in accordance with NR 811.42. - Collect samples of flushed water and submit sample results to Engineer every three calendar days after disinfection. Repeat entire disinfection process for test results not satisfying NR 811.42.		

The summary of work constraints in **Figure 6-1** have been developed to coordinate disinfection and commissioning amongst the contract packages, thereby reducing the work required to maintain chlorine residual and pressure prior to commissioning and mitigating the potential for requiring the disinfection process to be repeated by the contractor(s). The dates are tentative and are contingent upon when bidding occurs. The dates have been specified in the contract packages in the form of days after notice to proceed. The system-wide sequencing required by each contract package has been described in the specifications so that each contractor is aware of the others' obligations. The dates have been developed assuming the following items:

- **Station Suction Pipelines:** Disinfection will occur over five working days (one calendar week) using an AWWA C651 method selected by the contractor.

- **OPS:** Disinfection and startup of the OPS will occur over 10 working days (two calendar weeks) using an AWWA C651 method selected by the contractor. After substantial completion, the OPS and Station Suction Pipelines can be operated by MWW and serve the MWW Distribution System prior to disinfection and startup of the rest of Waukesha's new water supply system.
- **Water Supply Pipeline:** The Water Supply Pipeline will be disinfected using the slug method with a single 1,000-foot long slug conveyed at a rate necessary to provide the 3 hour contact time required by AWWA C651. Flushing will occur over a one-day period following disinfection. Laboratory results of bacteriological samples will be received three working days following collection. These assumptions result in a 22-working-day disinfection period for the Water Supply Pipeline (one calendar month).
- **BPS:** Disinfection and startup of the BPS will occur over 22 working days (one calendar month) using an AWWA C651 method selected by the contractor.
- **BPS Discharge Pipeline:** The BPS Discharge Pipeline will be disinfected using the slug method with a single 1,000-foot long slug conveyed at a rate necessary to provide the 3 hour contact time required by AWWA C651. Flushing will occur over a one-day period following disinfection. Laboratory results of bacteriological samples will be received three working days following collection. These assumptions result in an eight-working-day disinfection period for the BPS Discharge Pipeline.
- **WSCB:** Disinfection and startup the WSCB will occur over 10 working days (two calendar weeks) using an AWWA C651 method selected by the contractor.

Failure to complete disinfection in a timely manner will have monetary consequences for the contractors. For Contract Package 2, payment will be made at the actual linear feet of pipe up to a maximum of 90% of the contract unit prices per linear foot for pipe that will be carrying potable water. The remaining payment will be made after successful completion of disinfection as specified. Failure to meet the substantial completion dates (post-disinfection) for the Oklahoma Pumping Station and Contract Packages 2 and 3 will result in liquidated damages.



Notes:
1. Anticipated NTP for these contract packages is May 1, 2020.

Figure 6-1 Water Supply System Disinfection Process

SECTION 7 Transient Hydraulics and Air Management

The goal of the transient hydraulic analysis is to provide a cost-effective strategy to mitigate the impact (surge) from rapidly-changing flows. Transient mitigation devices in the form of pump discharge transient control valves, surge relief valves, air valves or surge tanks are typically required. Air management would also be needed to a) maintain capacity during normal operation by releasing entrained air and b) provide for smooth operations during the filling and emptying. Results from several methods for locating and sizing appurtenances were synthesized to develop a comprehensive approach for the Program. The following sections detail the development of the transient hydraulic models for the water supply system and the methodologies applied in the design of surge countermeasures.

7.1 Transient Hydraulics

7.1.1 Model Software and Capabilities

Hydraulic transients refer to flow phenomena that occur in between steady state conditions. Although gradual flow transitions also fall into the category, the focus is on changes that take place over short time periods. The impact of these abrupt changes in a fluid's momentum can be conveyed to parts of the system located several thousands of feet to miles away from the source. It is this combination of short time periods and the large scale of the pipelines that makes hydraulic transients challenging both to measure in the field and to model numerically.

Focusing on the latter method of analysis, the goal is twofold: to develop models of low "simulation cost" solutions that are also capable of capturing the physics of the phenomenon. The Method of Characteristics is a numerical analysis technique with a proven record of achieving this goal. The technique has been successfully applied to analyze a variety of engineering problems that defied analytical solutions. Since its first commercial implementation within the software engine of Liquid Transients (LIQT), the Method of Characteristics has been used extensively in the study of transient flows in pressurized pipeline systems. As with any method of numerical analysis, transient analyses based on the Method of Characteristics comes with specific limitations and assumptions. These assumptions should always be considered when one evaluates LIQT model results and are summarized as follows:

- Flow in pipes is one-dimensional.
- The velocity distribution is uniform throughout a pipe cross-section.
- The system is always primed (i.e. open-channel transients cannot be resolved).
- Both fluid and the pipe material are elastic (i.e. relationship of stress-strain is linear).
- Friction losses during transient events can be approximated using steady state flow formulae.

7.1.2 Model Development

The development of the water supply system transient models in LIQT followed standard modeling procedures (DNV GL, 2018a and 2018b). Sources of information to build the models were the pre-90% progress drawing set and supporting engineering documentation available at the time the study was carried out. For elements of the system lacking such information, the parameterization was performed upon close coordination with the design team, application of engineering judgement, and execution of sensitivity model runs.

7.1.2.1 Oklahoma Pumping Station (OPS)

The four pumps designed for the OPS were explicitly modeled in a parallel configuration with four respective suction and discharge lines. Each pump discharge line was equipped with a check valve, which was modeled for fast closure at the onset of reverse flow. Minor head losses due to fittings, instrumentation, and appurtenances were modeled with a lumped-sum coefficient (K-factor) applied on each pump line. K factors were identical to those used for the steady state hydraulic analysis.

The OPS pumps are equipped with variable speed drive units. These allow for a controlled (slow) starting process, which effectively mitigates the risk of startup-induced transients. The LIQT software's embedded capabilities to model the variable speed pump operation were used. The pump performance data utilized was based on manufacturers' pump curves for the flow and head required. Pump specific speeds and torques were calculated and imported into LIQT. Through this information, the LIQT model was able to generate pump data in all four quadrants of operation based on built-in libraries of dimensionless head-flow and torque-flow curves. This is an important step for the accurate simulation of the pumps' behavior in the wake of a power outage.

The suction header was modeled as a pressurized node receiving flows from the MWW Distribution System. Based on results from preliminary simulations demonstrating that high suction head results in increased transient impact, a fixed hydraulic head at elevation 728.5 feet was conservatively used.

7.1.2.2 Booster Pumping Station (BPS)

The parameterization of the BPS in LIQT closely followed the procedures described for OPS. Notable differences include the absence of check valves along the pump discharge lines. Instead, the presence of ratchets to prevent reverse rotation of the pumps was modeled using a module embedded in LIQT (DNV GL, 2018b). Losses at the suction side of the pump were modeled through an equivalent head loss coefficient. The water reservoir was modeled as a wet well with a fixed hydraulic head at elevation 985.0 feet.

7.1.2.3 Water Supply Pipeline

Both DIP and HDPE pipe segments of the pipeline longer than 12 feet were modeled explicitly. Due to LIQT's limitation in modeling pipe curvature, each one of the four HDPE pipe segments along the Water Supply Pipeline was approximated with three components: two sloped segments and one horizontal segment. Other geometrical and material properties (wall thickness, Young's modulus, Poisson ratio) were obtained from standard industry publications and textbooks (Beieler, 2012). LIQT's internal calculator was employed to estimate the acoustic wavespeeds for each pipe material equal to 3,492 fps for DIP and 1,140 fps for HDPE pipe.

The model was set up to calculate frictional pressure drop using C=150. This coefficient was adjusted for pipe segments including fittings and appurtenances to quantify minor head losses.

At the downstream end of the Water Supply Pipeline, the air-break at the water reservoir was modeled as a constant head at 1014.5 feet. Such a configuration is known to adequately replicate the physics of a free outfall without introducing numerical instabilities (DNV GL, 2018a).

7.1.2.4 BPS Discharge Pipeline

With the exception of material (use of DIP throughout), modeling of the BPS Discharge Pipeline followed identical procedures as those reported for the Water Supply Pipeline.

7.1.2.5 Appurtenances

7.1.2.5.1 Flow Control Valves

Isolation valves, which will physically exist in the system, but remain open during normal and transient flow conditions are not significant to the analysis and, therefore, were not modeled explicitly. The minor head losses introduced by such valves were incorporated for the appropriate pipe segment.

7.1.2.5.2 Air Control Valves

Air valve assemblies were added to the model on an as-needed basis to mitigate the transient impact. The parameterization of these assemblies did not follow a specific air valve model. Instead, a conservative assumption for the discharge coefficient was made (C_d=0.65) so that a wide range of options would remain available for the selection of the actual air valve devices. The boundary conditions at the atmospheric side of the air valves were modeled as fixed hydraulic head equal to the elevation at the top of the valves. Critical assumptions for attaining levels of air valve performance as described by model outputs include:

- The air valves will be mounted directly on top of the pipeline's crown.
- The vaults housing air valves are positioned as close as possible to locations where pipe changes slope (high points, beginning or end of horizontal pipe runs).

7.1.2.5.3 Pressure Sustaining and Reducing Valves

The pressure sustaining and reducing valves (16-inch diameter) installed on the Water Supply Pipeline and at the WSCB (one 10-inch and two 14-inch diameter) were explicitly modeled using LIQT's pressure control valve module (DNV GL 2018b). The operational logic of these valves was programmed to comply with the rationale detailed in **Section 5**. The physical characteristics of the valves were selected to emulate those of commercially available devices.

7.1.2.6 Fluid Properties

The fluid properties applicable to this transient modeling effort are included in **Table 7-1**. The entire water supply system is assumed to behave isothermally (i.e. filled with liquid at constant temperature). Furthermore, it was conservatively assumed that the liquid column is devoid of free air at the beginning of each model run.

Table 7-1 Fluid Properties used in LIQT Simulations

Property	Value	Unit
Temperature	60	Degrees Fahrenheit
Specific Gravity	1.0	dimensionless
Bulk Modulus of Elasticity	308,000	psi

Property	Value	Unit
Kinematic Viscosity	1.3×10^{-5}	ft^2/s
Vapor Pressure Head	0.5	psig

7.1.2.7 Initial Conditions, Time Step, and End of Simulations

To prevent spurious outputs due to “warm-up” effects, the models were set to run for 30 seconds under steady state conditions prior to introducing a transient-inducing event. The diminutive, 3.5-millisecond and 3-millisecond computation time steps were used for the Water Supply Pipeline and BPS Discharge Pipeline models, respectively. The rationale behind this selection was to facilitate convergence of the solution and to allow the fast-evolving phenomenon to be adequately captured throughout the computational domain. Through trial-and-error, 300 seconds were selected as the appropriate end point for the simulations, beyond which new information was found to have negligible impact on the results.

7.1.3 Sensitivity Analyses

Once the models had been built, a number of simulations were performed to establish confidence in the selection of model parameters. In particular, the liquid’s physical characteristics (specific gravity, viscosity, temperature, and vapor pressure) were varied within realistic ranges. Their effects were negligible. Similar findings were reported for parameters related to environmental conditions, such as ambient temperature and barometric pressure. Another round of model runs were completed to determine the transient impact as a function of targeted system characteristics. These runs ultimately demonstrated that the combination of high suction head and low pipe roughness constitutes the worst-case scenario for the transient evaluation and sizing of transient mitigation devices. Regarding the performance of transient mitigation devices, the way air valves are connected to the pipeline was evaluated. It was found that the farther the valve is from the pipe’s crown the less effective these devices were. Furthermore, the slope of the connecting pipe played a role, with worse outcomes reported, when the deviation from the vertical position increased.

7.1.4 Baseline (Unmitigated) Transient Impact Scenario

The LIQT models were used in basis of discovery simulations to better understand the system’s response to transient-inducing events. The ultimate goal was to define the maximum probable transient impact. This would, subsequently, serve as the baseline to evaluate the effectiveness of surge countermeasures. The simulations identified the case of simultaneous pump failure (power outage) as the critical scenario. Such result was in agreement with past experience of the modeling team and with published studies of similar pump and pipeline systems (Stubblefield et al, 2014).

To obtain the maximum probable transient impact, both pipelines were modeled conveying the design capacity flow rates of 15.1 MGD for the Water Supply Pipeline and 19.0 MGD for the BPS Discharge Pipeline. The suction head at the pumps was at its maximum level and C=150 was utilized. In addition to the operation of pressure sustaining and reducing valves per **Section 7.1.2.3**, flow control at the Water Supply Pipeline was achieved by programming the check valves installed at each pump line to close in less than a second, when flow is about to reverse. The instantaneous transient HGL envelope effectively summarizes the vast amount of outputs from a transient simulation, as shown in **Figure 7-1** for the baseline (unmitigated) transient impact scenario.

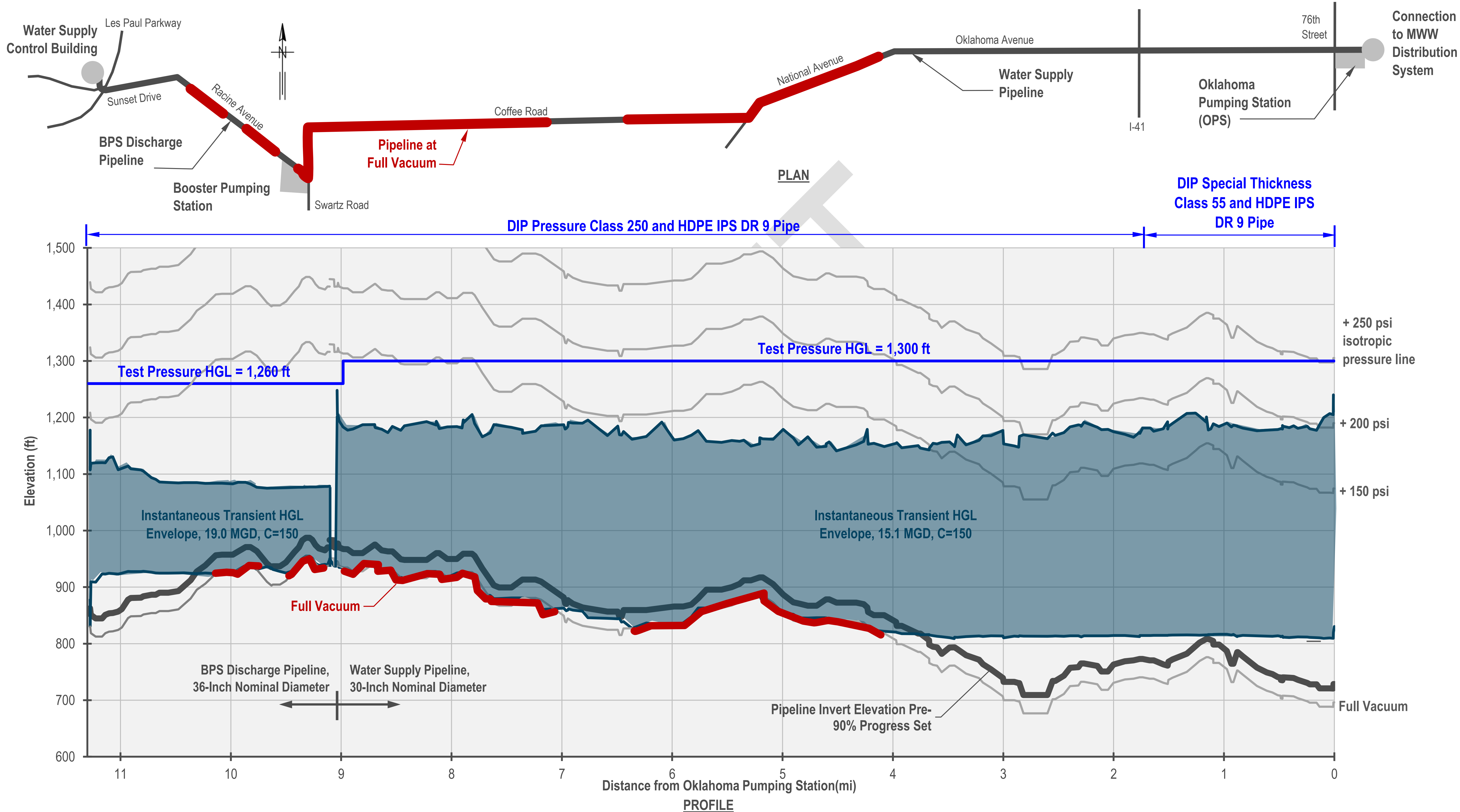


Figure 7-1 Non-Mitigated Instantaneous Transient HGL Envelope

As shown in **Figure 7-1**, positive pressure spikes exceed 200 psi with the maximum value recorded at the OPS discharge node. Negative pressures, all the way down to full-vacuum, were consistently reached at pipeline sections bordering local and global high points in the profiles of both the Water Supply and BPS Discharge Pipelines. These locations of full-vacuum pressure are emphasized in **Figure 7-1** with a **red** line. Along these stretches of pipe, there is high potential for vapor cavities and liquid column separation, whose important role in the dynamics of transients and the selection of the appropriate surge control devices (air/vacuum valves) will be discussed next.

Upon failure of pumps, the pressure within the water main cannot be sustained and naturally drops. At pipe segments located at mid-to-high elevations the drop assumes sub-atmospheric levels. Around local and global high points, the drop is even more dramatic, eventually reaching full vacuum. This wave of negative pressures is the so-called *downsurge*. Negative pressures act as radial forces that introduce additional compressive stress on the pipe wall, increasing the risks of structural deformation at the pipe joints and pipe failure by implosion. Another direct consequence of downsurges is the formation of vapor cavities. These cavities manifest as a discontinuity in the fluid's column – a phenomenon known as liquid column separation. In liquid column separation, the water column breaks into two parts (one upstream and the other just downstream of the cavity), which begin to move within the pipeline independently of one another. This growth phase of the cavity could be temporarily interrupted when the separated columns rejoin later in the evolution of the transient event. The collision is violent (slam). It culminates with a positive pressure spike in the time series, which is defined as *upsurge*. Episodes of alternating downsurges and upsurges repeat quasi-periodically and with varying intensities. Eventually, the magnitude of the peaks diminishes with time due to the dissipation of energy to heat by friction.

Using the knowledge about the transient impact on the water supply system, the next step is to establish quantitative and objective criteria to provide effective mitigation.

The transient impact from pressure upsurges is well studied and documented. It is incorporated in the design of pipelines through the metric of the maximum allowable surge pressure. DIP and HDPE DR 9 is furnished with 100 and 125 psi allowance for surge, respectively. The nominal maximum allowable surge pressures for the pipeline pressure classes are as follows. Note that throughout the baseline simulation, these maximum allowable surge pressures were not exceeded.

- **DIP Pressure Class 250:** 350 psi.
- **HDPE Pipe IPS DR 9:** 375 psi.

On the other hand, the documented impact of pressure downsurges (Autrique et al, 2016, Fleming et al, 2006, Ivetic 2004) has yet to be translated into a practical guideline. There is limited discussion in industry standards or the literature about a metric along the definition of a minimum allowable surge pressure. Research of the literature was complemented by direct communication with industry groups, such as DIPRA.

The major findings of these efforts are summarized in the following items:

- There is a lack of understanding on the impact that varying vacuum durations and repeating vacuum episodes (cyclic loading/fatigue) have on the structural integrity of DIP.
- Push-on joint DIP can withstand negative pressures up to -14 psi (which is close, but not equal to full-vacuum) without structural deformation, such as buckling.

- HDPE pipe can withstand greater negative pressures that DIP.
- Limited information or guidance is available regarding the impact of full vacuum pressures along DIP.

Combining the above with engineering judgement, criteria were established to characterize effective mitigation of the transient impact (upsurge and downsurge) as not to exceed values at any node and in any instance throughout the duration of the model run as follows:

- **Maximum Allowable Surge Pressure:** Test pressure as measured by HGL shown on **Figure 3-2**.
- **Minimum Allowable Surge Pressure: -**10 psi (globally).

7.1.5 Solution (Mitigated) Transient Impact Simulations

The transient mitigation strategy focused on the installation of Combination Air Valves (CAVs) along the pipeline. Preliminary simulations showed promise that a reasonable number of CAVs could achieve effective transient control. These simulations also confirmed that a surge relief valve would have no practical contribution in controlling the type of transients that this system is susceptible to. Therefore, such a solution was not pursued. Subsequent runs focused on optimizing the number, locations and geometry of the CAVs so that maximum benefit is achieved at minimum cost. The final simulation aimed at confirming that the surge control strategy would remain effective for the case that the Water Supply System has to function in so-called bypass operations.

The final configuration of transient mitigation measures included the following:

- **Water Supply Pipeline:** Four critical 4-inch diameter CAVs installed at the global and selected local points.
- **BPS Discharge Pipeline:** One critical 6-inch diameter CAV installed at the global high point.

The instantaneous transient HGL obtained for this final mitigated scenario is shown in **Figure 7-3**. Pressure upsurges are consistently contained to levels below 200 psi. For a good portion of the pipelines, the maximum pressure coincides with that obtained during steady state conditions. Furthermore, at no point did the downsurge assume values below the minimum allowable surge pressure. As a consequence, vacuum pressures did not materialize and no vapor cavities were formed.

7.1.6 Conclusions and Recommendations

The transient analysis of the water supply system can be effectively summarized with the following conclusions and recommendations:

Conclusions:

- Effective protection (within the established maximum and minimum allowable surge pressure thresholds) will be obtained through the installation of five critical CAVs as described above.
- No additional (beyond those already related to the system's operations) flow control protocols are necessary to achieve the transient mitigation reported herein.
- The pressure classes selected based on steady state hydraulics suffice to withstand transient hydraulics.

- The performance of transient mitigation appurtenances depends on the condition that these are adequately maintained and fully-functioning.

Recommendations:

- Findings and recommendations of this Report are contingent upon the selection of equipment (pumps and valves) that will be reasonably similar to the ones used in development of the transient hydraulic models for the water supply system. In case the specifications differ, the model and its results will need to be revisited to confirm hydraulic transients are properly mitigated.
- If comments are received from permitting agencies or authorities having jurisdiction that alters the pipeline alignment, the transient hydraulic model will be simulated based on the final pipeline alignment to confirm these findings. Any minor changes in the size and location of air valves would be completed prior to bidding.
- The Water Supply System Operations and Maintenance Manual (to be developed during construction of the Program) should incorporate pertinent operational protocols and recommendations related to the five critical transient mitigating CAVs.
- Transients due to pumps' startup (or re-start after a failure) can be controlled by: 1) slowly introducing water into the pipeline and 2) having pumps turned on one-at-a-time, until the Water Supply and BPS Discharge Pipelines are primed.
- The transient hydraulic model of the water supply system is a digital asset for WWU and MWW. As such, it is strongly recommended to be maintained beyond the design phase, so that the return from the investment for its development can be maximized. The capabilities of this "digital twin" of the physical system can be leveraged to achieve a variety of goals including optimization of operations, troubleshooting, and evaluation of future infrastructure upgrades.

7.2 Air Management

In addition to hydraulic transients, air valves are required to provide for air management along the water supply system. The following sections describe how air valves were also sized to manage air.

7.2.1 Air Release Valves (ARVs)

Air release valves (ARVs) exhaust small pockets of accumulated air that collect at high points during the normal operation of the pipeline. The presence of air pockets reduces the capacity of the pipe and increases head loss. It is, therefore, critical to make provisions for the effective removal of entrapped air, so that the entire system can operate efficiently. ARVs are designed to expel air in a controlled fashion and at modest rates, so that the risk from secondary transients due to a rapid expulsion of air is mitigated (Apollonio et al., 2016). For this reason, ARVs have a small orifice and are typically furnished in inlet sizes from 0.5 to six inches.

7.2.1.1 Methodology for Locating and Sizing ARVs

The selection and design of ARVs was primarily based on the guidelines of AWWA as detailed within the most recent edition of AWWA M51 (2016). Such recommendations are the industry's standard for the selection of design parameters such as the orifice size and location. The calculations were based on the design capacities and the assumption of 2% solubility of gas in the water flowing in the water supply system (at standard pressure and temperature). This methodology was applied over the length of the Water Supply and BPS Discharge Pipelines.

7.2.2 Air/Vacuum Valves (AVVs)

Air / Vacuum Valves (AVVs) serve the dual purpose of venting large quantities of air during pipe filling and admitting large quantities of air during pipe draining. Expelling the air present in the pipe as filling progresses is important because it prevents the formation of large air pockets in the pipeline. AVVs also prevent a vacuum from forming in the pipeline by allowing large volumes of air to be quickly admitted into the pipeline. Breaking the vacuum is an effective means to mitigate transient cavitation, which can occur during draining, pipe break, or other transient flow conditions. They are typically installed downstream of pumps and at high points in the system. It is important to note that AVVs are normally closed based on normal operating pressure and will not relieve the pipeline of small amounts of air. AVVs have a larger orifice and are available in inlet sizes from 0.5 to 30 inches.

7.2.2.1 Methodologies for Locating and Sizing AVVs

7.2.2.1.1 AWWA M51 – Pipe Filling and Emptying

When the water supply system is drained or filled for maintenance or emergency situations during operations, the air in the pipelines will need to be vented at the same rate that water flows into the pipelines. In accordance with AWWA M51, the pipelines should be drained and filled in a controlled manner with water flowing at approximately one fps. This translates into flow rates of 2,200 gpm for the 30-inch diameter Water Supply Pipeline and 3,170 gpm for the 36-inch diameter BPS Discharge Pipeline. Note that this fill rate does not apply to the initial filling of the pipelines, as the contractor may allow air to be expelled through blow-offs or other openings to allow a quicker fill rate. The second parameter to size AVVs is the pressure differential driving the flow of air. A target value of 2 psi was selected to maintain relatively low air speeds through the valve's orifice and, therefore, mitigate side-effects due to turbulence, valve slam and pressure spikes (Ramezani et al., 2015). The information will be included in the Water Supply System Operations and Maintenance Manual.

The number, location, and size of AVVs calculated for the pipe filling phase should suffice to allow air to flow in at the same rate as that of the water leaving the system during pipe draining. AWWA M51 calculations for filling and draining were applied throughout the pipelines.

7.2.2.1.2 AWWA M51 – Transient Mitigation

AWWA has published an analytical methodology for AVV sizing to mitigate the impact from transient-inducing events, such as power failures and pipeline breaks. Essentially, the goal is to control the resulting gravity flow, so that vacuum conditions and its adverse effects (column separation, transient cavitation) are avoided. The approach is relatively simple and relies on the installation of an AVV at every local high point along the pipeline. AVV sizing is performed based on the selection of the appropriate flow rate based on the allowable differential pressure of 5 psi needed to prevent pressures in the pipe from exceeding the threshold of collapse. By definition, this broad methodology encompasses a high degree of conservatism. In systems where a hydraulic transient model is available, it could serve as a means to cross-reference the results from the detailed numerical analysis.

7.2.2.1.3 LIQT Transient Hydraulic Modeling

The last method for locating and sizing AVVs to mitigate the transient impact involves the development and use of a model capable of detailed transient hydraulic simulations. The results from the LIQT model for the water supply system have already been presented in this section.

7.2.3 Combination Air Valves (CAVs)

CAVs combine the functions of an ARV with an AVV into one unit. Therefore, there is an economic benefit when both valve types are needed at the same location. CAVs contain both a small orifice for air release and a large orifice for large air release/vacuum into one assembly. Some applications will require an ARV and AVV to be manifolded together to provide benefits of both with a wider selection than what is offered with a single-body design. Single body CAVs are available in inlet sizes from one to eight inches, where dual body CAVs are available from one to 36 inches. Single and dual body CAVs were designed for smaller than 3 inches and 3 inches and larger, respectively.

7.2.3.1 Methodologies for Locating and Sizing CAVs

Since the installation of CAVs is simply a cost-effective means to obtain the benefits of both ARVs and AVVs, there was no need to apply additional methodologies to locate and size ARVs and AVVs. After review of the resulting locations of ARVs and AVVs, it was determined the water supply system would be provided with only CAVs at the locations and with the types and sizes recommended in the above sections. This approach also provides for ease of maintenance and operations, by reducing the number of different types and sizes of air valves that may be necessary as spare parts during operations. Seat durometers were determined based on the maximum normal operating pressure per manufacturer recommendations. Two air valve assemblies were designed for redundancy where required to mitigate hydraulic transients.

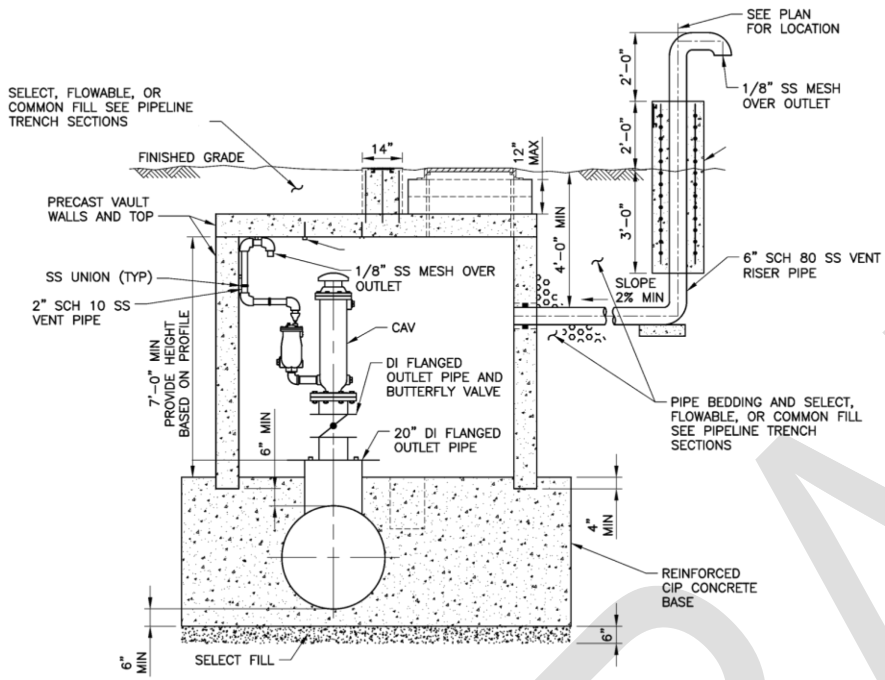
7.3 Air Valve Design

Air valves for the pipelines were designed based on the hydraulic transient modeling results and methods used to size air valves for air management purposes. Type I and II air valve assembly details are shown in **Figure 7-2**, while Type III air valves were designed along the Water Supply Pipeline in the City of Milwaukee in accordance with MWW standards. Outside of the City of Milwaukee, Type I air valve assemblies were placed at maximum intervals of 8,000 feet to allow access to the inside of the pipeline for inspection purposes and the remainder of the air valves were designed as Type II air valve assemblies to minimize cost. The size, type, number of air valves, and seat durometer are summarized in **Table 7-2** and the locations of the air valve assemblies are shown in **Figure 7-3.**

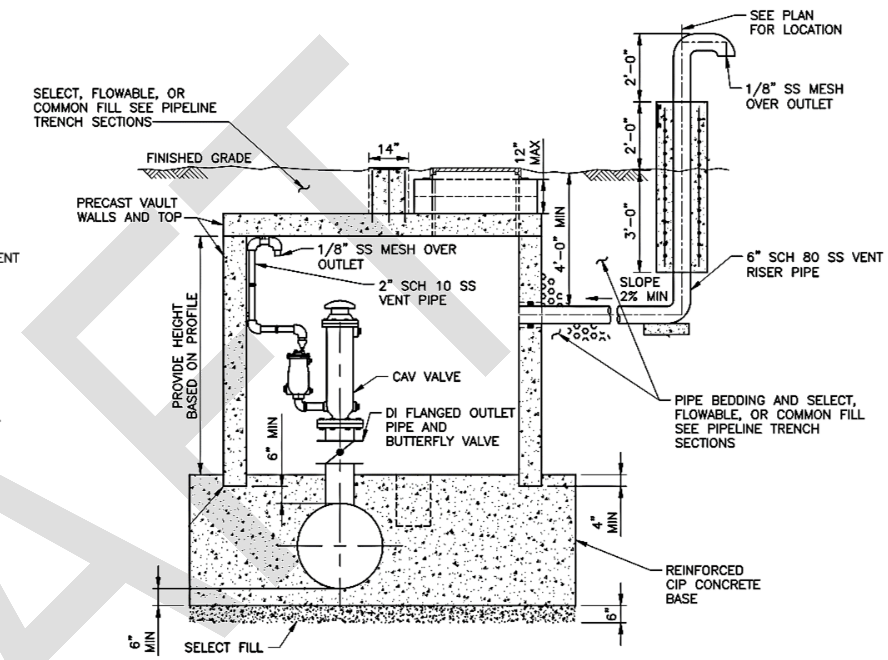
Table 7-2 Air Valve Assembly Schedule

Air Valve ID	Type	Size (in)	No. of Air Valves	Durometer Seat
Water Supply Pipeline				
AV-WS01	I	4	2	Standard
AV-WS02	II	3	1	Standard
AV-WS03	II	4	2	Standard
AV-WS04	I	3	1	Standard
AV-WS05	I	3	1	Standard
AV-WS06	I	4	2	Standard
AV-WS07	I	3	1	Standard
AV-WS08	II	4	2	Standard
AV-WS09	I	3	1	Standard
AV-WS10	II	3	1	Standard
AV-WS11	I	3	1	Standard
AV-01	III	N/A	1	-
AV-02	III	N/A	1	-
AV-03	III	N/A	1	-

Air Valve ID	Type	Size (in)	No. of Air Valves	Durometer Seat
BPS Discharge Pipeline				
AV-BD01	I	3	1	Standard
AV-BD02	I	6	2	Standard



Section – Type I, With Access



Section – Type II, Without Access

Figure 7-2 Air Valve Assembly Details

Notes:

1. The air valves were designed with a screened gooseneck within the vault and a vent riser pipe was designed from the vault to grade in accordance with NR 811.71.
2. Type I air valve assemblies were placed at maximum intervals of 8,000 feet to allow access to the inside of the pipeline for inspection purposes. The remainder of the air valves were designed as Type II air valve assemblies to minimize cost.
3. Type III air valves were designed in accordance with MWW standards and are not shown.

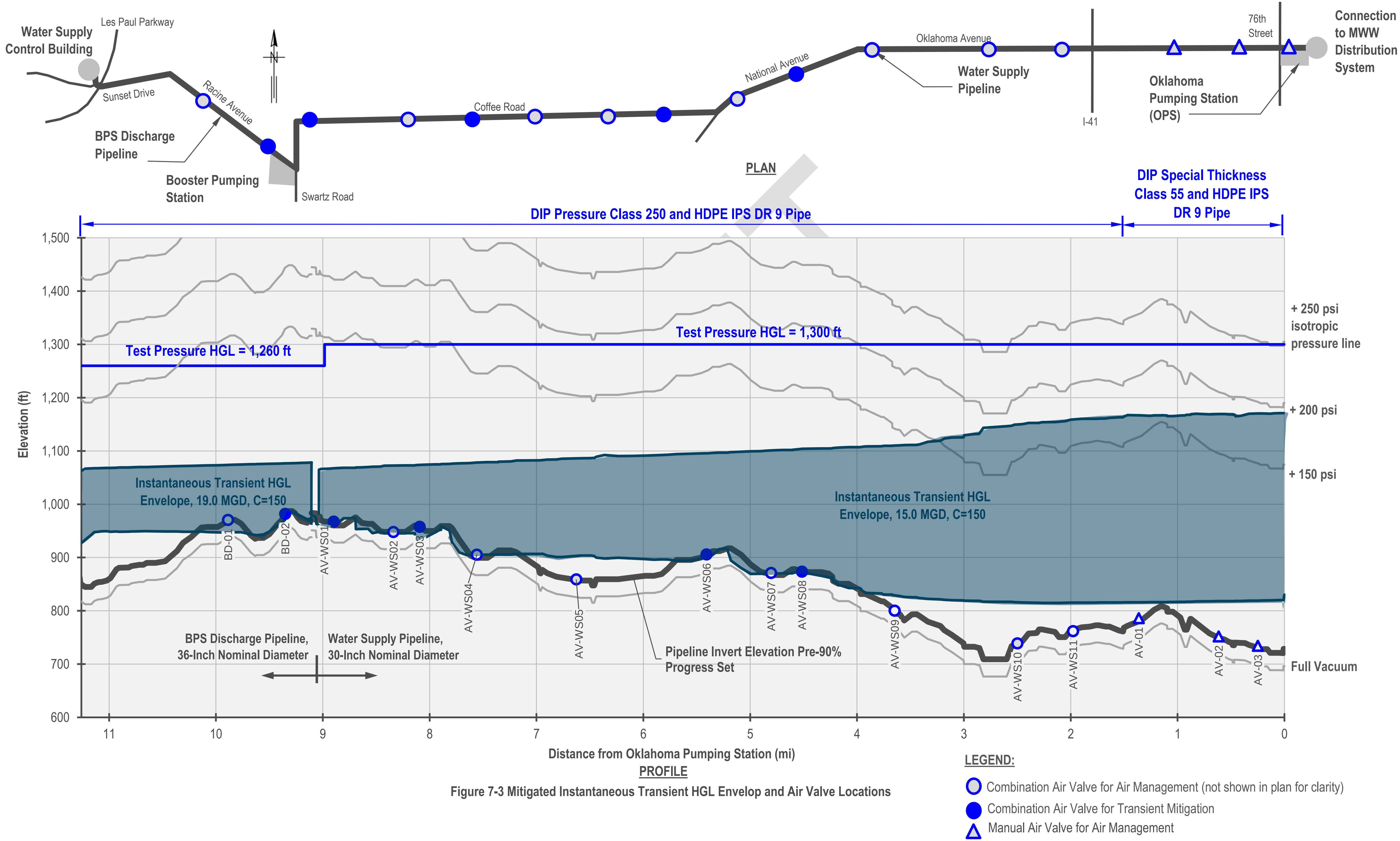


Figure 7-3 Mitigated Instantaneous Transient HGL Envelop and Air Valve Locations

SECTION 8 Program Water Supply System Costs

8.1 Opinion of Probable Construction Cost (OPCC)

An OPCC has been prepared in accordance with the AACE International's Recommended Practice No. 18R-97. The OPCC was developed using unit cost information from various resources in an effort to provide the best available information for each item, including manufacturer quotes, RS Means, and bid tabs from Southeast Wisconsin and Northeast Illinois. The diagram shown in **Figure 8-1** demonstrates the projected accuracy of the OPCC as the Program progresses as adapted from AACE International guidance. The OPCC in this document has been defined as Class 1 OPCC as shown in **blue** in **Figure 8-1**.

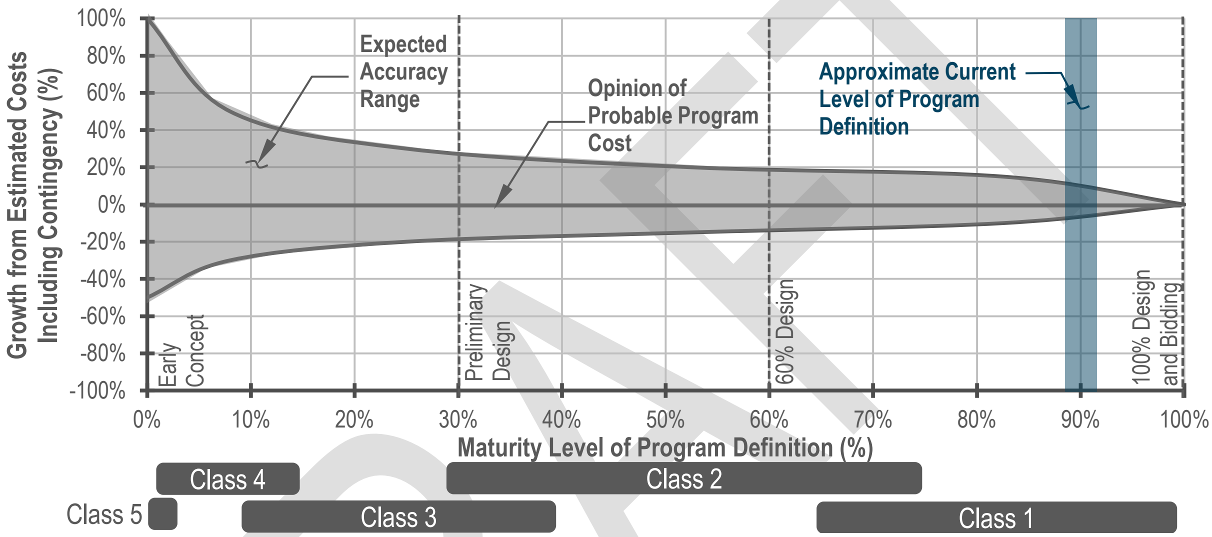


Figure 8-1 Cost Opinion Accuracy Diagram

Table 8-1 provides a Class 1 OPCC for each contract package associated with WWU's new water supply system. The contract packages that are part of the Program, but are paid for by entities other than WWU, have been included for reference. The OPCC was developed with a contingency of 15% and escalated to January 2021 dollars.

Table 8-1 Opinion of Probable Construction Cost

Contract Package		OPCC	
No.	Description	($ Million)	Notes
-	Oklahoma Pumping Station	-	See Note 1
2	Return Flow Pipeline, BPS Discharge Pipeline, Water Supply Pipeline Sections I, II, and III, and Station Suction Pipelines	48.3	See Note 2
3	Booster Pumping Station, Storage, and Chemical Facilities	40.6	-
4	Return Flow Pumping Station	-	See Note 3
5	Return Flow Pipeline	-	See Note 3
6	Return Flow Pipeline, 18-Inch Sanitary Sewer, and Outfall Facilities	-	See Note 3
	Total WWU Water Supply System Opinion of Probable Construction Cost	88.9	

Notes:

1. The OPS will be funded by MWW. A separate engineering report will be submitted by MWW as necessary.
2. The Station Suction Pipelines and approximately 0.6 miles of the Water Supply Pipeline are being paid for by MWW and have been excluded from this OPCC. The Return Flow Pipeline has also been excluded from this OPCC.
3. The Contract Package includes only infrastructure that supports WWU's new return flow system and has been excluded from this Report.

8.2 Operation, Maintenance and Replacement (OM&R)

Operation, maintenance and replacement (OM&R) costs have been developed to provide opinions of annual and Net Present Value (NPV) costs for WWU's new water supply system. The OM&R and NPV costs presented herein encompass the Program Elements of the new water supply system that WWU will own, operate and maintain.

The key assumptions used to develop the OM&R costs include the following items.

- NPV Gradient Series for a 20-year planning period, which is consistent with WDNR guidance on monetary analysis in NR 110, and an 8% Discount Rate and 3% Inflation Factor.
- Existing facilities operation and maintenance costs were escalated to July 2023, which is around the end of the water supply transition.
- When the new water supply system is operational, some of the existing facilities will have reduced OM&R costs due to the wells only being required for emergency backup operation, facilities being removed from service and other reduced load or ancillary costs that are being born by the new Program facilities.
- OM&R costs associated with the OPS, Station Suction Pipelines, and MWW-owned portion of the Water Supply Pipeline, are not included in this comparison as they will be built into the wholesale water rate per the water supplier contract held by WWU and MWW.

The Program facilities OM&R cost requirements were developed for WWU's Water Supply Pipeline, BPS, BPS Discharge Pipeline, and WSCB. The OM&R costs were escalated to July 2023 dollars. **Table 8-2** provides a summary of the existing facilities and Program facilities costs.

Table 8-2 Summary of Annual OM&R Costs

Description	OM&R Cost ($)
Existing Facilities:	
Existing OM&R Cost	$1,112,300
Anticipated OM&R Cost Reduction	($946,400)
Post-Program OM&R Cost Subtotal	$165,900
New Water Supply System Facilities and Pipelines:	
OM&R Cost Subtotal	$818,500
Total WWU Post-Program Water Supply OM&R Cost	**$984,400**
Total OM&R Cost Reduction from Existing to Post-Program	**$127,900**

SECTION 9 Conclusions

Under NR 108.04(2)(a), "All final plans and specifications submitted to the department pursuant to s. 281.41, Stats., and s. NR 108.03, shall be accompanied by a request for approval and by information pertinent to the design of the system, including general plans, construction details, specifications and an engineering report." The purpose of this Report is to satisfy this requirement for the above Program Elements being implemented as part of the Program by summarizing the approach used for making key design decisions that supported the development of the drawings and specifications, including the following:

- The approach for modeling steady state hydraulics, developing system curves, designing pipe size, test pressures, pumps, storage, pressure class, and restrained joints.
- Key design philosophies for the pumping stations and pipelines.
- The approach for modeling transient hydraulics, determining the type, size, and location for pipeline appurtenances required to mitigate hydraulic transients, and providing provisions for air management.

Note the Station Suction Pipelines and OPS will be owned and operated solely by MWW. The focus of this Report has been placed on the other Program Elements of Waukesha's new water supply system. Engineering reports for the Station Suction Pipelines and OPS would be submitted separately as necessary by MWW.

Route Study and Field Investigations

A route study was completed for the pipelines. Route alternatives were identified between a new OPS located on the southeast quadrant of Oklahoma Avenue and 76th Street, the new BPS located on the southwest quadrant of Swartz Road and Racine Avenue in the City of New Berlin, and the new WSCB located on the northwest quadrant of Les Paul Parkway and Sunset Avenue in Waukesha. The route alternatives were evaluated based on economic and non-economic evaluation criteria and scored via a Triple Bottom Line analysis guided by the Envision Rating System for Sustainable Infrastructure. Route Alternative M1 was selected as the preferred route. Field investigations, including site survey, geotechnical, environmental, wetlands, waterways, endangered resources, and cultural resources were subsequently completed to support design.

Water Demand and Steady State Hydraulics

Waukesha's new water supply system was sized to convey Waukesha's water demand as follows:

- **Water Supply Pipelines:** **15.1 MGD**, which is equivalent to the firm capacity of the OPS. The firm capacity of the OPS was determined in coordination with MWW based on MWW's operational preferences to supply sufficient demand to the reservoirs when periods of maintenance are needed which limit the hours of operation. The firm capacity is greater than the anticipated MDD of 13.6 MGD during a year where the ADD is the same as that approved by the Compact Council of 8.2 MGD.
- **BPS, Storage, and: Chemical Facilities** **15.75 MGD**, which was determined in coordination with WWU and is equivalent to Waukesha's existing PHD.
- **BPS Discharge Pipeline:** **19.0 MGD**, to accommodate future expansion of the BPS firm capacity to a flow rate equivalent to Waukesha's anticipated PHD during a year where the ADD is the same as that approved by the Compact Council of 8.2 MGD.

- **WSCB:** **19.0 MGD**, to accommodate future expansion of the BPS firm capacity to a flow rate equivalent to Waukesha's anticipated PHD during a year where the ADD is 8.2 MGD.

A steady state hydraulic model for the facilities and pipelines was developed based on the pipeline alignment and facility layouts. Hydraulics were simulated from static conditions (no flow) to the design capacities listed above. From the hydraulic analysis, a 30-inch Water Supply Pipeline and a 36-Inch BPS Discharge Pipeline sizes were selected. System curves were developed to support pump and valve selection at facilities. Pipeline test pressures were determined in accordance with AWWA C600, and pipe pressure classes and restrained joints were designed to accommodate the test pressures.

Design Philosphy, Pipelines

Pipe materials and joints were designed based on pipe size, hydraulics, constructability, WWU familiarity with material, and cost. To mitigate corrosion and provide for a longer service life, the pipelines were designed with two layers of polyethylene encasement – an inner layer consisting of V-Bio® Enhanced Polyethylene Encasement and an outer layer of standard polyethylene encasement, as well as sacrificial galvanic magnesium anodes, bonded joints, and test stations. The test stations will allow the ability to periodically monitor for corrosive signatures during operations so that proactive corrosion mitigation measures can be implemented if needed.

The horizontal and vertical alignments were developed for the pipelines considering pipe materials, joints, and construction methods, including open-cut and trenchless construction. Construction methods were selected based on surface features, existing utilities, and cost. Trenchless construction was utilized where open-cut construction was not specifically preferred due to surface features or permit requirements. Horizontal and vertical alignments of the pipelines were designed beyond pavement where feasible to reduce cost due to pavement replacement, flowable or select fill, and maintenance of traffic. Trenchless construction via jacking and boring was utilized as a means of mitigating surface disruption at rail and major road crossings and HDD was utilized to cross waterways, select wetlands, and some roads. Limits of construction were designed to accommodate the construction method and pipeline appurtenances.

Pipeline appurtenances were designed for operations and maintenance as follows.

- **Isolation Valves:** The pipelines were designed with butterfly valves that will serve to isolate portions of the pipelines for maintenance and repair scenarios. Isolation valves were placed at approximately two-mile intervals, while some valves were shifted towards trenchless construction segments to minimize additional restrained joint length. Isolation valves were designed to be direct buried except where specifically required to be located in vaults by the Wisconsin Administrative Code.
- **Blow-Off Assemblies:** Blow-off assemblies, consisting of a tee, branch, gate valve, and riser pipe, were placed at local low points in the vertical alignments to provide a means for draining the pipelines during startup, maintenance, or repair scenarios.
- **Air Valve Assemblies:** Air valves were placed at local high points along the vertical alignments to provide provisions for air management and transient mitigation. The air valve assemblies were designed in vaults with provisions for accessing the inside of the pipelines for inspection purposes at maximum intervals of 8,000 feet.

Design Philosophy, Facilities

Water Reservoirs

The water reservoirs will provide operational, equalization, and emergency storage and an air break between the MWW and WWU Distribution Systems. The effective storage capacity of the water reservoirs was determined to be 16.0 MG based on operational, equalization, and emergency storage. Two, 210-foot diameter circular, at grade, precast prestressed concrete water reservoirs with a side water depth of 33 feet were selected. The water reservoirs will have an inlet pipe rising 6-inches above the high water level to provide an air break from the Water Supply Pipeline. The water reservoirs were designed with a hydrodynamic mixing system to avoid dead zones, short circuiting, vertical stratification, and provide turnover to maintain water quality and assist in chemical addition.

Booster Pumping Station (BPS)

The BPS will utilize vertical turbine type pumps to convey water to the WWU Distribution System. Four pumps will be provided with three operating pumps and one standby pump. Each pump will have a 5.25 MGD capacity and discharge head of 145 feet and the BPS will have a firm capacity of 15.75 MGD.

Vertical turbine pumps were evaluated along with horizontal split case pumps. Vertical turbine pumps were selected due to the smaller footprint and subsequent cost savings in the capital cost for the BPS. Although the BPS will be provided with an initial firm capacity of 15.75 MGD, provisions for future expansion have been considered to accommodate the 19.0 MGD PHD associated with the approved 8.2 MGD ADD. These two options include replacing two of the pumps with higher capacity pumps or replacing all four pumps with higher capacity pumps. There is sufficient space and electrical capacity for this upgrade in the future when it is required.

To satisfy the minimum hour demand of 1.2 MGD, a recirculation line was designed to allow the pumps to stay above the minimum flow rate on the pump curve by recirculating flow from the discharge header to the suction header. Each pump will have a variable frequency drive to adjust pump speed and maintain the target HGL of 1,120 feet in the BPS Discharge Pipeline at the BPS. In the event of a failure or power outage, standby power will be provided by an on-site natural gas-fueled generator. The BPS will include security measures, including site access control and cameras.

Chemical Feed Facilities

Chemical feed facilities were designed based on the required chemical dosing at the BPS from the findings from a year-long pipe loop test. Chloramine will be used for disinfection, which is consistent with the disinfectant used by MWW. Sodium hypochlorite and liquid ammonium sulfate, the two components needed to create chloramine, will be dosed at two points, the water reservoir recirculation line and the BPS discharge line. Two chemical rooms will house bulk storage and day tanks, along with associated chemical equipment.

Water Supply Control Building (WSCB)

The WSCB will house one 10-inch and two 14-inch PSRVs to maintain pressure above 35 psi along the BPS Discharge Pipeline and reduce pressure to within the current operating HGL of the WWU Distribution System's Central Pressure Zone. The WSCB will also house the PRV interconnection between the Southeast Highline BPS and the BPS Discharge Pipeline to provide a hydraulic connection to Hunter Tower. In the event the BPS Discharge Pipeline pressure drops, such as in the event of sudden BPS pump stoppage or pipeline maintenance or failure, the PRV will open to allow flow from the Southeast Highline BPS or Hunter Tower to the BPS Discharge Pipeline and maintain maintaining pressure in the BPS Discharge Pipeline and at the BPS.

Leakage Testing, Disinfection, and Commissioning

The Wisconsin Administrative Code does not provide requirements specific to sequencing and disinfecting a long transmission main system with multiple facilities. A method for sequencing disinfection and commissioning of Waukesha's new water supply system has been developed and is included in this Report. The contractors could employ a different method during construction to more efficiently and effectively complete the work. However, key requirements necessary for the disinfection of Waukesha's new water supply system have been specified in order to support the successful completion of the water supply transition and allow the same or comparable disinfection methods to be implemented. Each contractor will be responsible for providing leakage testing in accordance with AWWA C600, disinfection in accordance with AWWA C651, and commissioning of infrastructure within the limits of their contract package. Constraints were specified in order to reduce the effort to maintain chlorine residual and pressure by the contractors prior to commissioning and to mitigate the potential for requiring the disinfection of a given Program Element to be repeated. Payment will be withheld from the contractor until after completion of disinfection.

Transient Hydraulics and Air Management

A transient hydraulic model for the facilities and pipelines were developed in LIQT software based on the pipeline alignments and facility layouts. Hydraulics were simulated for a sudden loss of power and stoppage of pumping while conveying the design capacities of the pipelines and facilities. Transient mitigation devices in the form of air valve assemblies were designed along the pipelines to mitigate hydraulic transients. Air valve assemblies were designed to maintain capacity during normal operation by releasing entrained air and by accommodating filling and emptying during startup and maintenance.

SECTION 10 References

American Water Works Association. (2005). *Disinfecting Water Mains; Fifth Edition*. Manual C651-05.

American Water Works Association. (2009). *Steel Pipe: A Guide for Design and Installation; Fifth Edition*. Manual M11.

American Water Works Association. (2009). *Ductile-Iron Pipe and Fittings; Third Edition*. Manual M41.

American Water Works Association. (2016). *Polyethylene Encasement for Ductile-Iron Pipe Systems.* Manual C105-10.

American Water Works Association. (2016). *Air-Release, Air-Vacuum, & Combination Air Valves; Second Edition.* Manual M51.

American Water Works Association. (2017). *Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings*. Manual C111-17.

American Water Works Association. (2017). *Installation of Ductile Iron Water Mains and their Appurtenances*. Manual C600-17.

Apollonio, C., Balacco, G., Fontana, N., Giugni, M., Marini, G., & Piccinni, A. (2016). "Hydraulic Transients Caused By Air Expulsion during Rapid Filling of Undulating Pipelines." *Water*, 8(1), 25.

Autrique, R., & Rodal, E. (2016). "Experimental Verification of Steel Pipe Collapse under Vacuum Pressure Conditions." In IOP Conference Series: Earth and Environmental Science. Vol. 49, No. 5, p. 052008

Beieler, R. W. (2012). *Pipelines for Water Conveyance and Drainage*. Reston, VA: American Society of Civil Engineers (ASCE).

DNV GL (2018a). *LIQT Theory and Model Planning Guide.* pp. 124

DNV GL (2018b). *LIQT User's Manual*. pp. 670

Fleming, K. K., Dugandzik, J. G., & Lechavellier, M. (2006). *Susceptibility of Distribution Systems to Negative Pressure Transients*. American Water Works Association. pp. 113

Ivetic, M. (2004). "Forensic Transient Analyses of Two Pipeline Failures." *Urban Water Journal*, 1(2), 85-95.

Ramezani, L., Karney, B., & Malekpour, A. (2015). "The Challenge of Air Valves: A Selective Critical Literature Review." *Journal of Water Resources Planning and Management*, 141(10), 04015017.

Stubblefield, N. D., Ahmad, R., & Scioscia, M. (2014). "Managing Atlanta's Water Transmission Main with Transient Analysis: How Making Fine Adjustments Extends Asset Life." In Pipelines 2014: From Underground to the Forefront of Innovation and Sustainability (pp. 1546-1557).

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